THE LONG HEAT

Climate Politics When It's Too Late

Wim Carton and
Andreas Malm

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For Ebbe, Nadim and Latifa

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Preface

Into the Long Heat

Things bad begun make strong themselves by ill.

William Shakespeare, *Macbeth*

Stopping climate change, we have been told for decades, is the greatest challenge humanity faces. ‘No challenge – no challenge – poses a greater threat to future generations,’ one could hear politicians proclaim until the words ceased to register.[1] But climate change was not stopped. It was not stopped in time, before the critical limit of 1.5°C was breached; instead, emissions continued to soar and investment in fossil fuels accelerated when profits reached an all-time high. The challenge for humanity then undergoes a migration. What do we do about climate breakdown once we are caught up in it? Can we live with the crisis that was not stopped? Is there a way to find safe and stable ground under our feet again? If so, what would it take?

The original front of climate politics was called *mitigation*: the closing down of the sources of warming, first and foremost fossil fuels; the cutting of emissions; the shift to other kinds of energy. Fossil capital won an easy victory and progressive forces suffered a grievous defeat on this front. The result is the present conjuncture of too-lateness. We offered a history of it in *Overshoot: How the World Surrendered to Climate Breakdown*. What follows is an attempt to map the sprawling fronts opened up next. When the breakdown is an ongoing fact, something has to be done; it becomes impossible to ignore; the realities of a collapsing climate make themselves felt with escalating severity. Three main options remain. We can do *adaptation*: learn to live with the warming to the best of our abilities. We can do *carbon dioxide removal*: take CO_2 out of the atmosphere and put it

back in the solid Earth so as to re-establish a liveable concentration of the gas. We can do *geoengineering*: block some of the incoming sunlight and cool the planet down. In the pages that follow, we shall inspect these potential measures for sustaining life after the climate revolution that did not happen, trace their frontlines into the discernible future and ask: can any of this work under current constellations of power? Can it make up for the absent transition? Will progress on these secondary fronts be possible without a revival of the struggle for mitigation and a destruction of fossil capital, now so far behind schedule? What can be achieved in adaptation, removal, geoengineering under the prevailing order – what would success here look like?

If this book is a triptych, however, its parts are not symmetrical. The first is a brief primer on adaptation. This pursuit is difficult to demarcate from the everyday experience of global warming: wherever people feel its effects, they try their best to cope. A study of adaptation could span the frontiers from Belize to Bangladesh and explore how the multitudes of the global South deal with everything from wells drying out to homes being washed away; indeed, such a study – climate suffering in the South still massively underrepresented in the literature – is called for. But this is not it. Our quick survey rather introduces a central problematique of the rest of this inquiry: what happens when dominant classes deploy technologies for managing the breakdown they refused to stop.

Technology is the force poised for rollout on all three fronts. On the second, it goes by the name ‘negative emissions technologies’: various devices for drawing already-emitted CO_2 down to Earth and keeping it there. Overshoot, or the transgression of a temperature limit such as 1.5°C, is a function of too much CO_2 having been emitted; and so discussions about the prospects for a return to safer levels have focused on removing the gas. Too-lateness is defined by an excess of CO_2. Continued – perhaps even good – life on this planet hinges on the capacity for its negation. The second part is thus a more comprehensive inquiry into negative emissions technologies: how they have been imagined, how they would work, what their drawbacks might be, who champions them and for what purposes. Because of the centrality of technology to the overshoot conjuncture, some engagement with the nuts and bolts of the proposed contraptions is here necessary. Moreover, any navigation on the terrain of excessive warming

presupposes literacy in the latest climate science. Chapter 7, ‘Breaks in the Time Machine’, offers one reading of it; if we have sometimes, mostly in jest, thought of this project as a Marxist IPCC report of a readable nature – one political and one literary attribute setting it apart from the real thing, among other differences – this is our excursus on the ‘physical science basis’, in the lingo of the Panel. Here is the frame within which every facet and front of climate is constituted. What form will the breakdown take in the years ahead? The later chapters of the second part are concerned with the political economy of negative emissions technologies: the strategies by which fossil capital appropriates them for the prolongation rather than inversion of business-as-usual. Those devices might end up drawing even more fossil fuels to the surface for burning. But were they not meant to have the opposite effect?

At an earlier stage, the term ‘geoengineering’ often encompassed negative emissions technologies, but in line with more recent usage, we shall reserve it for those meant to intercept solar radiation: the topic of the third part. Here is the biggest gun in the drawer of overshoot management. While examining it, we shall devote some attention to dimensions of the psyche, the all-too prevalent tendency to deny and repress this catastrophe. A contention will be that technologies for suppressing the warming are bound to set off novel spirals of disaster and dissent – the stuff of climate politics when it’s too late. Does this rest on a general rejection of modern technology? Emphatically not: to adapt a phrase from Lenin, we seek concrete analysis of the concrete technology. One cannot lump together, say, floatovoltaics and stratospheric aerosol injection and denounce them with the same vehemence or endorse them with identical affection.[2] Neither blanket hostility to the tech on offer nor sweeping enthusiasm is of much help. Both are dogmas better replaced with close empirical investigations. Not all technologies are equal; not all are good or bad; some have the potential to sow unparallelled destruction on Earth.

Overshoot was a history of the present conjuncture, and this sequel continues in the same vein. We attempt to write a history of what is coming – which is, of course, by definition impossible; the future can only be turned inside out and known through the past that leads up and into it. We delve into the intellectual history of removal and geoengineering (and very briefly, adaptation). We aspire to follow the lines from their conceptual prehistory via their contemporary use and further into scenarios, more or

less plausible, of their full-scale mobilisation. But the future, of course, will not just copy the present with more ink; simple extrapolation is an impermissible procedure. The chaos of this breakdown will throw up unexpected events aplenty. History must shade into speculation: we shall move back and forth between past and present and future tense. We have subtitled this book *Climate Politics When It's Too Late*, but we might as well have called it 'climate technology' or 'science' or 'psychology when it's too late'. Politics, however, is the region that binds the others together. Precisely because of the chaotic complexity of this long heat, readers may not come out of this book with ready-made slogans to paint on banners or ten-point programmes to print or share on social media. But for those aligned with the climate movement and concerned about struggles to come, there should be ample material to chew on. What we aim to do here is unfold a map of the emerging fronts and their basic coordinates.

As anyone who has picked it up will readily perceive, this is a long book that asks a lot of the reader. We have here taken a leaf from what we consider to be the two greatest cli-fi novels yet written: *The Ministry for the Future* by Kim Stanley Robinson and *The Deluge* by Stephen Markley, both epic panoramas of the breakdown – the latter coming in at 900 pages – composed with the conviction that this subject deserves sustained attention. If we have approached the long heat, in this work of non-fiction, with only a small fraction of their liveliness, we shall have accomplished something. Like the finest writers of cli-fi, we believe that we are in for a rough ride over the coming decades, one that may well include a fair degree of violence.

Before we start, a short recap of the main arguments and concepts in *Overshoot* is in order. In the Paris Agreement, negotiated at COP21 in 2015, the nations of the world committed themselves to 'holding the increase in the global average temperature to well below 2°C above pre-industrial levels and pursuing efforts to limit the temperature increase to 1.5°C'. The latter message sounded loudest. It was confirmed in 2018, when the IPCC published its Special Report on 1.5°C: if warming were to exceed this level, catastrophic impacts would begin to kick in. It had to be avoided.[3] To respect the limit, it was soon made clear to all concerned parties, there could be no new fossil fuel installations: no new oil platforms, gas terminals, coal mines or similar pieces of infrastructure. A moratorium

followed by a rapid phase-out of fossil fuels would be the only chance. What then happened on the ground was the diametrical opposite. Starting in 2021, a profit bonanza on a scale never before seen swept the fossil fuel industry – or, primitive fossil capital – and incited a frenzy of fresh investment in exploration, extraction, transportation and refinement of oil and gas and coal. Things were out of control.[4] The years between the Special Report and the bonanza marked the beginning of the *overshoot conjuncture*: the period in time when the dominant classes demonstrate their constitutional inability to shut down the drivers of global warming in the face of fast-approaching limits. The inability then begins to be converted into other projects for managing the fallout.

But the road to the conjuncture has long been paved by *programmatic* overshoot, the idea that emissions should be allowed to continue and the average temperature to exceed the fixed limit – such as 1.5°C, but it could also be 2°C (and potentially higher still) – followed by a return to lower levels. The world can allow itself to fly above 1.5°C. Once the boundary has been crossed, the glut of CO_2 can be taken out through negative emissions technologies (singled out for particular proficiency was Bioenergy Carbon Capture and Storage, to which we shall return below). The incubator for this idea was a type of computer model known as Integrated Assessment Models, or IAMs. When modellers ran their IAMs, they would learn that a 'temporary' overshoot and subsequent return would be the cheapest, smoothest, most efficient pathway. The goal would first be missed and then hit. Carbon dioxide removal would perform the trick that should not be attempted with early swift mitigation.[5] The idea developed into a broader *overshoot ideology*: various ideological practices bound together by the understanding that emissions are out of control and we have no project for bringing them under control and so we must try ventures other than mitigation of the classic sort.[6]

At some point, of course, emissions will have to be slashed. Otherwise, the overshoot would go on and worsen forever. The ideologists argue that instruments for managing the fallout – adaptation, removal, geoengineering – will merely 'buy time' for the mitigation now postponed. The edge will be taken off the catastrophic impacts; meanwhile, the world will complete the delayed task and come out on the other side clean of fossil fuels. There will be no further distractions or prevarications. The three types of instruments

will not entice anyone to stay longer with fossil fuels. A component of overshoot ideology, this is *rationalism-optimism*, or the belief that technologies for hemming in the unstopped catastrophe will be deployed in a rational and optimal fashion and will not further aggravate an already bad situation.[7]

But the real origins of this family of ideas does not reside in computers. It rests in a deep bed of material circumstances in the department of fossil fuel production. For companies to extract oil and gas (and, to a lesser degree, coal), they must sink enormous amounts of capital into their fields: platforms, terminals, derricks, pipelines, ships, trucks, refineries and all the cumbersome rest. A globe-spanning landscape of fixed capital, it primes its owners for defence of business-as-usual. If a capitalist invested in an offshore oil platform in the year 2024 and drilling is declared illegal in 2025, he will lose tens of billions of dollars. He will not recoup his investment, let alone see any profit from it. The never-ending investment in fossil fuels therefore creates a self-reinforcing inertia and obstructive force blocking a switch to other forms of energy. A transition would render the whole landscape of fixed capital in fossil fuel production worthless: the assets would be 'stranded' or, more precisely, capital would be subjected to *political destruction*. Most vulnerable would be the oil and gas companies themselves, but banks and asset managers and other types of capitalist entities with stakes in their businesses could likewise be hit by a shock of all times, if mitigation were ever to commence for real.[8] Against this danger, the present mode of production posits *capital protection*. Overshoot in all its forms is capital protection. The activity can be divided into two distinct but related categories: *active* capital protection, undertaken by capitalists with interests in fossil fuels, directly and on their own initiative; and *passive* ditto, pursued by others on their behalf.[9]

Note that what is protected here are not the basic needs of humanity, for the flow of energy (or renewables) is not technically inferior to the stock (or fossil fuels). In fact, since the 2010s electricity can be generated far more cheaply with solar and wind than with any of the latter. A 100 per cent flow economy is within technical reach. Humanity would have everything to gain from transitioning to it at the highest possible speed.[10] But solar and wind can never yield profits anywhere near those from fossil fuels, and since the bonanza of the early 2020s, the gap has only widened.[11] The

overshoot conjuncture is not an outcome of necessities in the human struggle for daily bread, but of the failure to execute capital destruction. And this failure compounds itself.

As we write this, in March 2025, the world has, naturally, moved deeper into the overshoot conjuncture than when we finished *Overshoot* one and a half years ago. The year 2023 was another inauspicious milestone for warming. It saw a jump in temperatures almost double the 'normal' rate of increase; ocean heat surged; on land, month after month shattered previous records, some by as much as 0.5°C at a time. December was 1.78°C warmer than the pre-industrial average; half of all days in 2023 exceeded a 1.5°C increase; two days in November even surpassed the 2°C limit.[12] The year as a whole ended 1.45°C above the average – the hottest on record.[13] And then 2024 continued in the same groove.

It wasn't supposed to. In the summer of that year, the El Niño, spreading warm water and air from the Pacific, swung into a naturally cooling La Niña: but with zero relief. Had nature ruled, temperatures would have dropped during 2024.[14] Instead, they leapt even higher and steeper. Old records crackled like twigs in a bonfire, from one corner of the globe to the other: Egypt hit 50.9°C, Mexico 52°C, Laos 43.7°C, Mali 48.5°C.[15] The worst drought in at least a century gripped southern Africa. In several countries, it wiped out more than half of the harvest; in the worst-afflicted parts of Mozambique, farming families had to scrape out roots to manage one meal per day.[16] This was the kind of southern climate calamity that would never make any northern headlines, one just sorted into the low, sizzling background noise from the wretched of the earth. Smoke from burning rainforest and wetland draped the cities of Brazil.[17] Water levels in the Amazon were the lowest ever recorded.[18] Extreme heatwaves in western Africa matched extreme downpours in western Asia, and in January 2025, scientific bodies looked back on the year that had ended and distilled the figure 1.55°C: for the first time, one whole year had crossed the Paris limit.[19]

In the strict, technical sense, 2024 thereby marked the onset of overshoot. There still remained – perhaps – a theoretical chance to reduce that year to an unfortunate blip and stay below 1.5°C in the coming decades by immediately obliterating CO_2 emissions from fossil fuels.[20] But that was

not the direction in which the world was moving. Instead the frenzy carried on. Global investment in the production of oil and gas increased by 9 per cent in 2023, and then by 7 in 2024: nearly one tenth *more* capital sunk into their fields, year-on-year.[21] 'Today's investment trends are not aligned with the levels necessary for the world to have a chance of limiting global warming to 1.5°C,' the International Energy Agency tersely remarked.[22] In the three years after the bonanza started, primitive fossil capital increased its annual expenditure on oil and gas exploration by more than one third.[23] The central arena of the frenzy was the US. In 2023, it pumped more oil and gas than any country had ever done in history, and issued a record 758 licences for new projects, nearly as many as in the three previous years combined. Behind the US followed the rest of Anglo-America – the UK, Australia, Canada – plus Norway, five affluent countries together accounting for the bulk of the licences handed out in the 2020s.[24] It was a banality to point out that if a Mutarara farmer couldn't find food, a New York investor couldn't care less.

On some measures, the dominance of the US was staggering: this single country held two thirds of all private financial capital invested in fossil fuel production, a sum ten times larger than that originating in the second country on the list (Canada).[25] A bank like JPMorgan just couldn't stop funding a company like ExxonMobil. Indeed, the former retracted its nominal commitments to moving away from fossil fuels, as did the other giants of financial capital: just as the breach of 1.5°C was officially announced, the six biggest US banks unabashedly withdrew from the 'net zero banking alliance'.[26] On the other side of the Atlantic, BP gave up its last pretentions of toning down fossil fuels and went all in on virgin assets in the Middle East and Gulf of Mexico.[27] Shell moved the same way, as did Equinor, whose CEO offered an artless explanation: 'We are scaling down our investments in renewables and low-carbon solutions because we don't see the necessary profitability in the future.'[28] Such was the order of the day.

Gas boomed.[29] So did coal, on a global scale, thanks to China, underlain by India, Indonesia, Australia in an Asian arc of black stone. It partook of the bonanza, investment sticking to an upwards curve.[30] The construction of new Chinese coal plants in 2024 reached a scale unseen in a decade.[31] Solar also boomed (unlike wind), and in the EU this source of electricity eclipsed

coal in 2023: testimony to what *could* be achieved, even on a continent moderately blessed with sunshine.[32] An actual switch from stock to flow appeared to be underway in the power sector of the Union. It consequently registered a fall in CO_2 emissions by no less than 8 per cent in 2023: rare positive news in an ever-more rapidly warming world; signs of a regional coal-to-renewables transition.[33] But overall, the picture remained one of addition. If solar panels proliferated, they did so like lace on a constantly growing cake of fossil fuels. For climate, the effect would then be no better than sugar paste on shit: the atmosphere continuously overfilled with waste products, as long as fossil fuels are extracted – not to mention investment in them ballooning. Global CO_2 emissions had not even stagnated by the mid-2020s, defying recurring prognostications that a peak was imminent. Onwards they grew, by around 1 per cent in 2023 and 2024, mitigation as elusive as ever.[34]

As if to seal this refusal to mitigate in blood, the US in 2024 re-elected as its president Donald Trump. In April of that year, old acquaintance Harold Hamm organised a dinner at Mar-a-Lago to which executives from ExxonMobil and lobbyists from the American Petroleum Institute and other dignitaries of the industry were invited; in their honour, the Republican candidate railed against migrants, renewed his promise to ‘drill, baby, drill’ and asked for a donation of one billion dollars.[35] And the money did flow his way. No other class fraction contributed as much to the Trump campaign as primitive fossil capital.[36] In his inaugural speech, he reciprocated: ‘We have something that no other manufacturing nation will ever have, the largest amount of oil and gas of any country on Earth, and we are going to use it – let me use it.’ There were no equivocations about the material substratum: ‘We will be a rich nation again, and it is that liquid gold under our feet that will help to do it.’[37]

On his first day in office, Trump notified the UN that his country would leave the Paris Agreement. He declared a ‘national energy emergency’, the inverse of a climate emergency.[38] He would tackle it by making it easier to build pipelines and gas terminals, opening up Alaska – the next Saudi Arabia, in his eyes – to drilling without restraints, cancelling emissions standards for cars and, not the least pointedly, waylaying any further expansion of solar and wind.[39] He ordered a complete stop to permits for wind farms that ‘degrade our national landscape’.[40] An initial freeze on

solar arrays and other renewable infrastructure on public land would last for sixty days. Solar and wind were conspicuously excluded from the very definition of ‘energy’ in the emergency declaration.[41] Trump stormed into the White House to make America ‘energy dominant again’, by pumping even more oil and gas, exporting even larger volumes, radicalising the trends set in motion during the Obama years and boosted by Biden.[42] This flurry of initiatives was enacted against the backdrop of parts of Los Angeles turning into cinder and ash, whole neighbourhoods looking more like Jabaliya than Mar-a-Lago after the wildfires of January 2025, which, in the world as a whole – in the midst of a La Niña phase – was the hottest January on record, 1.75°C above the pre-industrial average.[43] Overshoot had found its president.

The anatomy of far-right anti-climate politics was dissected in some detail in *White Skin, Black Fuel: On the Danger of Fossil Fascism*, written during the first Trump presidency; early in the second, what stood out was the extreme ordinariness of such politics. Unlike in 2016, Trump was now the bona fide representative of overshoot. He cared nothing for 1.5°C or 2°C. He dispensed with the euphemisms and embellishments and harmonised words with deeds. Tendencies in the material base of this mode of production had converged with his ideas: he brought the destructive forces straight to the superstructural surface.

But for precisely this reason, the second Trump presidency presaged the opening of the secondary fronts. He and his associates were, of course, as wedded as ever to denialism of the most classical brand: ‘Curb all this silliness about CO_2 emissions,’ one of the guests at the Mar-a-Lago dinner begged him; ‘I’m skeptical of the idea that climate change is caused purely by man,’ asserted his vice president.[44] But such diehard obstinacy would not change the fact of the matter. Rather it ensured that climate politics would explode in other, derivative forms. If the dominant classes successfully stuck to their refusal to mitigate – of which Trump was the sign and seal – they, and everyone else on this planet, would have no choice but to deal with the real emergency in some other fashion. If a house is allowed to catch fire, and if there is no other house to live in, the act in itself necessitates some type of urgent measure. The meaning of the second coming of Trump seemed to be this: our fate now is to adapt, or to remove, or to engineer, or to do some of that in combination. Can this make up for

what has been lost? Might the story of climate breakdown yet turn out fine in the end?

PART I

Adaptation Is a Run through the Battlefield

1

The Battle of Sainte-Soline

On 25 March 2023, we woke up in a tent camp turned marshland after a night of incessant heavy rain, like the proverbial music festival in which revellers melt into the mud. But the many thousands camping on this site had not (only) come to make merry. As the morning bells rang, we lined up in three columns and marched out of the camp in solemn order. A sense of foreboding prevailed.[1] The police had encircled the camp with flying checkpoints, making the trip there a protracted game of hide and seek; but now they were nowhere to be seen. The general expectation was that they were gearing up for a major battle. So were the activists, in their own manner: in the ‘blue finger’ where we marched, many covered their faces with balaclavas and gas masks, donned helmets and carried wooden shields painted in blue; between the ubiquitous blue overalls and the low leaden skies, the scene moved through shades of aquamarine. A brass band gave rhythm to hundreds of muddy boots. Someone beat a drum and played a sombre flute, as if the crowds were marching through the fields to confront the defenders of a feudal castle; and indeed, as soon as we approached the target, a new hue of bluish grey entered the spectrum – clouds of tear gas – accompanied by the staccato whistles and bursts of grenades.[2]

During the decade before this battle, as the lands of Europe warmed by between 1.5°C and 2.5°C – one degree faster than the global average – the French countryside began to wither in the heat.[3] Crops shrivelled for lack of water. Farmers did not have enough to sustain irrigation. Fields turned a barren yellow, while fires stalked the remaining forests. The curve shot up in the early 2020s, with the combined drought and heatwave of the summer of 2022 setting a new record for the continent; in France, January and

February 2023 – the winter months just before the battle – saw thirty-two consecutive days without rain.[4] The long-term viability of agriculture in the west and south of the country appeared to be in question. What could be done to save it? French authorities imported a model first tried out in Spain: the construction of enormous water reservoirs, to be known as *mégabassines*.[5] Craters covering more than a dozen hectares, with plastic sheathing as floor, they would each hold as much water as nearly 300 Olympic pools.[6] But it would not be captured from rainfall. The water would, rather, be pumped through pipes, from the ground and streams and their run-off in the fields. By extracting it in wintertime – so the reasoning went – and storing it in the open tanks for the crucial spring and summer months, farmers would be guaranteed access to this ever more precious liquid: a technology for adapting to hotter and drier times. By the time of the battle, there might have been some fifty *mégabassines* in operation or various stages of development, and more were coming.

They attracted the ire of a broad segment of critics. Even if undertaken in winter – a season itself increasingly arid – the pumping of water would leave the surrounding lands high and dry. Small farmers unconnected to the *mégabassines* would have even less to survive on, as would the various species inhabiting the catchment areas. Centralising all of that water in giant ponds was not a recipe for thrift. Under the ever-warmer sun, more of it would evaporate; instead of percolating through the ground and replenishing the aquifers, it would be collected at the surface, where it would be most directly exposed to the heat. And the spigots were reserved for some farmers only. The *mégabassines* were designed for the largest agribusiness companies and their corn fields in particular, the products from which would largely be exported, as fodder for livestock as far afield as in China.[7] This was not an agricultural model for exiting the climate crisis. It would take France and the rest of the agro-industrial world deeper into it, while wasting water, excluding the less fortunate from its use, desiccating lands and threatening the vestiges of rural biodiversity.[8] If this were a technology promoted as adaptation, it had to be smashed.

Or so thought a growing coalition of farmers, trade-unionists, conservationists, autonomists, climate activists, scientists, parliamentarians of the left and others, many of whom marched under the umbrella name of Les Soulèvements de la Terre, or the Uprisings of the Earth (a cause and a

milieu captured in Rachel Kushner's *Creation Lake*, another fine exemplar of environmental fiction). During the 2010s, the beacon of radical environmentalism in France was the ZAD of Notre-Dame-des-Landes, a vast tract of land occupied by militants originally bent on stopping a planned airport.[9] They succeeded, spectacularly. The airport was scrapped and the ZAD remained: a local victory in the struggle for mitigation of the classic kind. Out of the ZAD emerged the core of Les Soulèvements de la Terre in late 2021 to push the climate movement in Europe onto novel terrain. For the first time, it took aim at a project advertised as adaptation.[10] In October 2022, nearly 7,000 people swarmed through the fields of Sainte-Soline in the west of the country, towards the construction site for one detested *mégabassine*. As some militants held off the police in pitched battles, others stormed the site and spent two days tearing apart pipes and fences in a revelry of sabotage.[11] Half a year later, they were back, at least three times as many.

But this time, the police had built a fortress around the reservoir of Sainte-Soline. Some 3,000 cops from the gendarmerie and other units stood guard, their cars and vans and four-wheelers forming rings of steel. The most heavily armed cops were positioned around the embankments, their commanders on top of them. When the tip of the 'pink finger' arrived – carrying a huge wooden figure of the bustard, a totemic pheasant species threatened by the *mégabassines* – it was showered in tear gas.[12] These were not the militants prepared for confrontation. The latter arrived with the blue finger, and then the field in front of the reservoir was transformed into a battlefield proper: contingents covered with shields charged against the police lines with stones, fireworks, Molotov cocktails. Before long, the first van was on fire, a thick, oily coil of smoke curling into the air. Four more police vehicles would be set ablaze. A few individuals managed to breach the cordon and briefly enter the site before being repelled. From their ramparts, the police rained down weapons of various kinds – tear gas grenades, stun grenades, sting ball grenades, flash balls – with little discrimination, in amounts reaching above 5,000 projectiles fired in less than two hours.[13]

Demonstrators began to fall around us. One screamed from a bloody wound in the back of the leg. Another seemed to have an eye shot out. Paramedics tried to attend to the injured, while crowds behind the frontlines

watched in a daze or tried to keep dancing to the nervous techno beats from a sound system. Two demonstrators were hit so badly that they hovered between life and death, one awakening from coma a full month after a grenade entered his head; a further 200 were wounded – faces disfigured, hearing lost, shrapnel in calves – as well as, more lightly, some 50 policemen.[14] After two hours of ferocious fighting, the crowds, traumatised by the scale of the violence meted out to them, began to drift back towards the camp. Some minor pipes connected to the reservoir were sabotaged along the way. By all accounts, it was the most intense confrontation involving an environmental movement in the global North to that date.

'The Battle of Sainte-Soline', as the events became known, announced the struggle against a particular kind of adaptation: when resources that become increasingly scarce in a warming world are centralised under the domain of private property, those who lose out will be worse off than before. From their perspective, the arrangement will represent a 'maladaptation' – exacerbating the problem, not ameliorating it.[15] Eventually they might fight back. Indeed, cases of spontaneous resistance against adaptive projects had begun to pile up on all six continents by the early 2020s, mostly in the form of refusals to follow orders to relocate from declared climate disaster zones.[16] Les Soulèvements de la Terre took such defiance to a higher level of organised militancy, in the heart of the global North.

It paid off. In December 2024, a court in Bordeaux declared the *mégabassine* in Sainte-Soline 'illegal'. Because it risked destroying the habitat of the endangered bustard, the reservoir – already filled with water – could be legally used the following summer, but never again.[17] Three other unfinished constructions in the vicinity had their permits suspended. The battle of Sainte-Soline seemed to have been won by the movement; but the same court validated a dozen other *mégabassines*, ignoring scientific research on how poorly they treated the matter of water in an ever hotter, drier countryside.[18] By the time of this writing, it was not clear whether the ruling represented a half-victory for Les Soulèvements de la Terre and its allies, or something bigger or smaller. But it was eminently clear that, with its repeated exercises in mass militancy, this had become the most vibrant and successful environmental movement in the global North; and that the front around the *mégabassines* remained fluid and open.

More generally, the battle of Sainte-Soline heralded a logic of climate politics when it's too late. Once the dominant classes have failed to contain global warming, because they cannot bring themselves to phase out fossil fuels, they will need to do something else to keep their order in place and maintain a semblance of normality. The causes of the warming run rampant, but something has to be done to rein in the process and its symptoms: some technology must be rolled out for getting things under control. When this happens, there is a *multiplication of secondary fronts* beyond that of mitigation. Novel technologies designed and deployed by the dominant classes elicit their own discontent. It does not have to take the form of violent confrontation – local riots, global wars – which rather mark the pis aller. But all of the main technologies for managing overshoot give rise to new rounds of antagonism. In this sense, Sainte-Soline was a portal into the overshoot conjuncture. Precisely because it is too late for climate politics, there will be so much more of it.

2

The Rise of Muscular Adaptationism

When the message of the warming underway was first picked up in the 1970s and ’80s, a common response was stoic acceptance: we will learn to live with it. Organic intellectuals of the US bourgeoisie advocated adaptation as the natural solution. In *The Great Adaptation* – a fitting twist on Karl Polanyi’s classic *The Great Transformation* – Romain Felli has chronicled the history of how scientists, economists and other credentialled experts loyal to the prevailing order embraced the knowledge of anthropogenic global warming as the foretelling of a fate.[1] Although the combustion of fossil fuels was identified as its source, closing it down was a nonstarter: it would cost the economy a fortune and require bureaucracies to rule by fiat. As when any species encounters changes in its environment, adaptation would be the smoother, more flexible option.[2] One pioneering climatologist, Steven Schneider, published a book in 1976 called *The Genesis Strategy: Climate and Global Survival*, in which he advised the world to prepare for the turmoil ahead like the prophet Joseph counselled the Pharaoh to deal with alternations between seven years of plenty and seven years of dearth: save grain from the former to distribute during the latter (a doctrine that could have been plastered on the *mégabassines*).[3] Half a century before the overshoot conjuncture, the warming was here accepted as preordained.

And adaptation was a matter of technology. In a piece representative for the moment, printed in *Nature* in 1991, influential US climate scientist Jesse Ausubel made the case for adaptive tech – much to be preferred over attempts to ‘slow down the greenhouse express’.[4] The first examples he

gave were ‘cisterns and dams to store water’ in, followed by ‘tractors to speed rapid harvests, and new crop cultivars to reduce susceptibility to drought’.[5] He then veered off into a grand theory of technological development and modernity as such. Humans consistently invent things to make climate matter less and less: food preservatives, refrigerators, air conditioning have allowed them to set their preferences regardless of how warm or cold it might be; windshield wipers enable them to see in the rain. Modernity is a project for ‘climate-proofing’ society.[6] We can now fly to whatever weather we happen to like, enter shopping malls with perfectly optimised temperatures, erect oil platforms on the highest seas, extract rubber from petrochemicals rather than from plants subject to drought and flood. Ever since the shift to steam power, society has been bidding a long farewell to climate: while water mills and sailing ships were hostage to weather conditions, coal set humanity free.[7] Successful adjustment to warming is not a matter of breaking with fossil fuels. It follows from staying on top of their waves and surfing into a future even more dissociated from climate – there will be fully enclosed indoor cities, desalination plants, pipes for collecting freshwater and transferring it to places in need. Ausubel concluded with a rousing call for optimism.

> The general direction of change in technology and civilisation is heartening for those anxious about climate change. The trend is towards systems that are less vulnerable to climate. It would seem to be sensible to maintain this course and not revert to reliance on such technologies as sailing ships and water mills that are more sensitive to climate. The highest need is probably to assure the inventive genius, economic power, and administrative competence that make many technologies useful in adapting to climate available to the most people.[8]

Adaptation, in this moment, was forthrightly conceived as a substitute for mitigation. Instead of getting off fossil fuels, humans should equip themselves with technologies for living with their attendant heat; indeed, for someone like Ausubel, the quest was for more of the gifts coming from those same fuels. But as climate science and politics matured in the 1990s, the equation was inverted. In the year after Ausubel’s essay, at the Rio summit, the United Nations composed its Framework Convention on Climate Change, the foundational document of every Conference of the Parties or COP held since then. It did mention the need for adaptation, in passing.[9] But this pursuit was subordinated to that of stopping CO_2 concentrations from rising. The world committed itself to ‘prevent

dangerous anthropogenic interference with the climate system' – to halt the greenhouse gas express, in Ausubel's terms; a ranking of priorities opposite to his.[10] The signing countries – rich ones in particular – were enjoined to mitigate the problem at its source by limiting their emissions. The negotiations that followed proceeded from this core premise. Mitigation stayed in focus, from Rio to Kyoto and Copenhagen; in a charitable reading, all the way to Paris. Adaptation remained an auxiliary, although, towards the end of this period, more and more voices were raised on its behalf.[11] The world, they argued, urgently needed to cut emissions, but there was already damage in the pipeline. People also needed cushions. Mitigation and adaption were not substitutes for each other: *both* were called for, and each could, in the best case, facilitate the other.[12] Contrary to the original substitutionism of people like Schneider and Ausubel, the COPs and the IPCC reports of the first two decades of the twenty-first century laid down the ideal of a combination.

In the early 2020s, however, the equation changed again, as the heat began to bite deeper into people's lives. Mitigation stood revealed as an epochal failure thus far. There had been no limit to emissions, only a secular rise. In late 2022, the *Economist* pronounced the ambition to cap the warming at 1.5°C dead in the water; 'no matter what, the world now faces more floods, droughts, storms and wildfires.' Adaptation must be put front and centre. 'Fortunately,' the magazine continued, 'a lot of adaptation is affordable. It can be as simple as providing farmers with hardier strains of crops and getting cyclone warnings to people in harm's way.'[13] When the disasters struck, top leaders of state apparatuses adopted much the same rhetoric. In the summer of 2021, rivers in western Germany rose and burst their banks and flushed away villas, filled villages with mud, ripped up roads and railways and killed 196 people, leading chancellor Angela Merkel to visit the area and declare: 'Germany is a strong country. We will stand up to this force of nature'; but politicians like her did not initiate the necessary emissions cuts.[14] Instead they focused on the need for wiser zoning and warned against building next to rivers.[15] When floods again hit the strong country in the summer of 2024, environmental minister Steffi Lemke observed, 'It is becoming increasingly clear that we need to protect ourselves better against the consequences of the climate crisis.' She did not

call for an immediate shutdown of the German lignite mines, but for stronger dykes to hold back the masses of water.[16]

During a lull in the wildfires that scorched western France in the summer of 2022, President Emmanuel Macron posed for pictures while shaking hands with firefighters. He praised them for beating ‘the beast that is these wildfires’ and vowed to ‘stabilise the fire, go after the victory and rebuild’. Enduring victory would come in the form of a larger fleet of water bombers. There would be a ‘major national project’ of reconstruction; but the president had not a word to say about the activities of Total, the single largest corporation headquartered in France.[17] The Canadian state sent in armed forces to remove fallen trees and other debris after storms in 2022, and to battle wildfires in 2023.[18] The idea that it would send armed forces to expropriate fossil fuel companies belonged to a fantasy world. Indeed, the same Prime Minister Justin Trudeau who sighed that ‘things are only getting worse’ on the storm front and called for more resilient infrastructure had a track record of hailing investment in megaprojects for oil and gas, including the latticework of pipelines covering Canada.[19] When flash floods and landslides tore through South Korea, President Yoon Suk Yeol urged his citizens to ‘accept climate change is happening, and deal with it’, by which he meant preparing for the next blow.[20] He did not comment on the extreme carbon intensity of the South Korean export industry.[21]

A couple of weeks later, the deadliest American wildfires in a century burned through Hawaii, and the *Wall Street Journal* – known for having voiced climate denial longer than most; not known for advocating a phase-out of fossil fuels – had a solution on offer: ‘Better tech could save lives in a world of bigger, faster, more devastating fires.’ More precisely, ‘a wide array of new technologies are being tested and deployed that can alert authorities minutes after a fire starts. These include tower-mounted cameras that use artificial intelligence to identify smoke, and sensors that are installed just above the forest floor, sniffing out fires using a kind of electronic nose.’ The *Journal* spoke to startups working on advanced satellites and other devices to be ‘stitched into comprehensive “fire intelligence networks”’.[22] If only the tech would set off the sirens in time, the burning world could be brought under control.

We may call this species of ideology *muscular adaptationism*. It says: these extreme weather events are now a fact of life, but they can be

managed if only powerful enough technologies are put in place – dykes, water bombers, electronic noses, *mégabassines*. If the nation gets its act together and reinforces its disaster preparedness in a more or less military fashion and patriotic vein, life will go on. The forces of nature, the beasts can be beaten back. What muscular adaptationism does not say – and this silence defines the ideology – is: 'Wake up folks, if we don't rid ourselves of fossil fuels, we're going to have more and more of these disasters until we can't live any longer.' Symptoms are to be combatted, not causes and drivers.

The folly at work here is the belief that it is possible to adapt to a world careening towards 2°C and 3°C and even more degrees of warming. It is a truism that it becomes harder to live with the heat the more of it there is.[23] Adaptation to half a degree is fairly feasible – to six or twelve times as much, far less so. One survey found that the effectiveness of any given adaptation measure – storing water, improving irrigation, protecting against floods, shifting planting dates – will decline by an average of 70 per cent for every degree; but this is a guesstimate, and the fall is not likely to be linear.[24] There could be sudden breakdowns in buffering capacity. Indeed, muscular adaptationism began to take hold just as the world approached tipping points in the climate system, beyond which, as we shall soon see, adaptation loses its meaning. And the ideology had the function of *speeding up* that approach, because it let fossil fuels off the hook. Where mitigation should have been, it insinuated the illusion that one could proof society against a collapsing climate: quench ever-worsening fires with more water bombers or smarter electronic noses; dam up ever-growing shortages and excesses of water behind walls. But one cannot pull oneself up by technological bootstraps forever. Unmitigated warming will sooner or later overtop the defences, and muscular adaptationism paradoxically brought this breaking point closer, by redirecting attention to 'better tech'. Such tech did not need to have any material existence at the moment of disaster. It was not clear that Germany actually overhauled building rules, or that France expanded its fleet of water bombers, or that 'fire intelligence networks' were within reach: it was the *promise of future delivery* that did ideological work in the heat of the moment. Substitution had become real, even if the technical solutions had not.

The process that started to spin in the early 2020s has been felicitously called a 'doom loop'. 'The consequences of the crisis and the failure to

address it draw focus and resources from tackling its causes, leading to higher temperatures and ecological loss, which then create more severe consequences, diverting even more attention and resources, and so on.'[25] By championing adaptation instead of mitigation between the mid-1970s and early 1990s, bourgeois intellectuals adumbrated this loop; it then became a practical proposition in the 2020s, when the refusal of the dominant classes to close down the sources of the heat began to take more serious effect. All signs were, at that moment in time, that the loop would keep revolving.

3

Let Them Build Sea Walls

The problem of adaptation is, of course, far more pressing in the global South than in the North. South–North remains the central axis of the distribution of vulnerability. The latter concept has its etymological roots in the Latin *vulnus*, for wound; more specifically, in *vulnerabilis*, a word used by the Romans for the condition of a soldier lying wounded on the battlefield.[1] Someone who is vulnerable to the blows from climate breakdown is someone who already carries a wound from struggles in society.[2] Adaptation is typically defined as 'the process of adjustment to actual or expected climate and its effects' – in less anodyne words, those who lie wounded must rise up and run through the hail of blows that constitutes this crisis.[3] If they are successful, they have adapted well.

After five centuries of violent subjugation of southern peripheries under the European core and its American extensions, the wounds are deepest and most extensive in the former. But they are also distributed along class lines. It takes resources to survive a disaster, and under capitalist property relations, these are concentrated in the hands of owners.[4] To offer just one case, the Nile delta of Egypt is an illustrative battlefield. Subsumed under the imperial metropolis since at least the 1840s, this region has been riven by ever-deepening class divisions since the neoliberal reforms of the 1990s.[5] Flat like a mattress stretched out towards the Mediterranean, it is hypersensitive to sea level rise. One metre might inundate one fourth of the delta.[6] It houses nearly two thirds of the agricultural land of Egypt: no country risks losing as much to the seas.[7] But this is not merely a future prospect, because the Mediterranean has already begun pushing saltwater

into the delta. Made up of silt, the soil is porous like a sponge. When the pressure of the sea rises, saltwater is pumped through it, seeps deep into the ground and rises to the surface in pools multiplying along the coast. As the water evaporates, it leaves a white crust of salt, killing the fertility of the land.[8] Since the turn of the millennium, salinisation has crept further into the delta and created serious trouble for those cultivating it; in the late 2010s, 57 per cent of farmers in northern districts complained of increased salinity, 84 per cent of decreased crop productivity.[9] How do they learn to live with such changes?

They elevate the land above the rising water table by spreading sand on it. By the 2010s, a common sight on the northern fringes of the delta were piles of sand, little yellow pyramids brought in from the deserts, waiting for excavators to level them so as to lift the land above the salt bubbling up. The additions had to be made more and more frequently. Sand, however, is the traditional enemy of the farmer, something to be kept out from the fields; crops do not thrive in this substance. To make the elevation work, the sand must be mixed with manure and fertilizers. Pumps have to be installed to inject freshwater from the Nile. Fences of reed must be maintained to prevent the now sandy soil from blowing away. Crop varieties more resistant to salt might also be selected.[10] All of these inputs, however, come in the form of commodities fetching a price on the market: sand transported by trucks became steadily more expensive and, already in the early 2010s, often cost far more than what a smallholder could afford. Excavators, fertilizers, pumps, fences caused ballooning expenses for maintaining productivity (and much of this equipment had, of course, a fossil fuel footprint). Who could pay to live this way? Not everyone: the demands of adaptation knocked down farmers wounded from decades of neoliberal onslaught. In the 2010s, the lands closest to the sea were progressively abandoned by poorer smallholders, who could no longer stay on top of the salt, gave up, sold their plots and disappeared into the impoverished multitudes of the cities. Land was further concentrated in the hands of rich farmers and agribusiness companies.[11] On this battlefield as on so many others, those already armed and protected were best fitted to prevail.

An analogous process played out through the construction of sea walls. In the 1990s, property development in resort towns on the delta coast took off, havens for wealthy Cairenes during the ever more sweltering summer months. But the rising sea threatened the beaches, villas and hotels with

erosion and worse. Breakwaters in concrete were built as bulwarks to signal to real estate investors that continued expansion was risk-free and encourage vacationers to keep coming. Villages inhabited by fisherfolk and farmers were left without any similar protection. Water would then be stopped by the structures in front of the resorts and pushed towards the gaps nearby. As a result of the selective walls, erosion and storm surges *worsened* in the plebeian neighbourhoods, in a logic similar to that of the *mégabassines*.[12] A resource increasingly scarce in a warming world – safe coastal land – was centralised in the hands of owners of private property: and those left by the wayside thereby came to have even less of it.

The logic here pertains to the mainstream conception of adaptation, rooted in a version of social Darwinism.[13] Much as when a species faces the selective pressure of a dramatically altered environment, the less fit organisms and populations will perish. The call to adapt, which rang out first in the 1970s and then again, far louder, in the 2020s, often amounted to little more than ‘Go and protect yourselves as best as you can’ – or, in an echo of Marie Antoinette, ‘Let them build sea walls.’[14] In 2007, as adaptation rose on the agenda of climate politics, Desmond Tutu famously warned that ‘we are drifting into a world of “adaptation apartheid”’.[15] When the overshoot conjuncture dawned, there were no more limits to this drift than to the temperature rise itself.[16]

4

Revolutionary Adaptation?

But every Marie Antoinette and apartheid system faces revolutionary alternatives. In Egypt, the second decade of the millennium opened with a real opportunity: the Egyptian revolution, central act of the Arab Spring. At the height of the mass demonstrations in Tahrir Square, one adaptation specialist wrote: ‘Hosni Mubarak’s regime was not doing enough to protect the country in a changing climate. Let’s hope Egyptians win this fight for a new government. It will be the only way they can win the longer-term fight against the rising sea.’[1] In this moment, another adaptation seemed possible. One could imagine the collectively organised elevation of farmlands through redistribution of sand from the deserts to the northern frontiers. There could be free delivery to all farmers. The agricultural cooperatives that sustained a degree of popular self-sufficiency on the land during the Nasserite era, only to be destroyed by Mubarak in the 1990s, could be resuscitated to coordinate a fair distribution of excavators, fertilizers, pumps, fences, salt-tolerant cultivars.[2] Sea walls could be built for everyone.[3] Mubarak did fall, but the counter-revolution succeeded, of course, in driving any emancipatory impulses in Egyptian society deep underground, where they barely caused a tremor for a whole decade. But new eruptions cannot be ruled out, here or elsewhere. From that possibility – if only theoretical – stems a more hopeful scenario: a healing of the wounds; a collective rising that equips people with the appropriate shields. Would that win the longer-term fight against the rising sea and other blows?

In the scientific literature, this scenario is known as ‘transformational adaptation’ – an attack on the root causes not of global warming, but of vulnerability to it.[4] Concrete proposals have ranged from democratic

empowerment of impacted communities – one could imagine councils of the vulnerable – to remuneration of the 'adaptive labour' people on the frontlines currently have to do without payment.[5] Another has been drawn up for the city of Malmö, where the present authors live. The largest city in flat southern Sweden, it is susceptible to sea level rise and severe flooding from downpours. The worst incident of the latter, as of this date, occurred on 31 August 2014, when 100 millimetres of rain fell in twenty-four hours and deluged basements and streets across the city.[6] (One of us had a newborn daughter who left the maternity ward in Malmö three days earlier; she is likely to experience more such events.) In a banal, fractal iteration of the global pattern – this being a heavily segregated city – working-class people of colour live in neighbourhoods with weak systems for water catchment. Their basements are more likely to flood, their sewage to overflow, their drinking water to be contaminated. Rich white districts are better covered.[7] By the early 2020s, municipal authorities seemed to care little for such injustices in their planning – a disregard shared by the city's climate activists. Before Les Soulèvements de la Terre, few in the European movement bothered with adaptation. One group of activist-scholars proposed that activists get over this inhibition and, more concretely, that social centres in Malmö reach out to the most vulnerable, organise them for and in the next disaster and push for a transformation of the urban fabric: real adaptation can only be achieved by the wounded classes themselves.[8]

The strategic vision beginning to emerge in the early 2020s was potentially a very broad one.[9] Every disaster opens an opportunity for intervening on the battlefield, building popular agency and attacking the fortresses of adaptation apartheid. Drought is a case in point. In Cape Town – designated a white area during apartheid, suffering a series of severe droughts from the mid-2010s onwards – the richest 13 per cent of the population consumed more than half of all water in the early 2020s. Informal dwellers and other working-class people of colour made up 61 per cent of the city's population but had to make do with around a quarter of its water.[10] Such apartheid went global in these years: during the hot and dry French summers, golf courses would be exempted from bans on watering. But then activists from Les Soulèvements de la Terre and other groups began to invade the courses and fill up their holes with cement and tear into them with pickaxes.[11] To paraphrase Public Enemy, the future of this long

heat holds nothing else but opportunities for such confrontation. But could they possibly secure a win in the *longer-term* fight?

One here sometimes encounters a mirror image of muscular adaptationism, which might be called progressive ditto. It says that the root causes of vulnerability can be addressed through a 'revolution or major realignment in the balance of class forces' – or, more specifically, that 'climate change, while a significant challenge, *can be managed* with the correct adaptive responses'.[12] But even a communism of sand would be drowned by a sea that keeps rising. It might be possible to fairly elevate the lands of the northern Nile delta by a few decimetres; but if the sea rises by one or three or five metres, nothing – not even underground sea walls for everyone – could hinder the southward march of the salt.[13] And, as we shall soon see, such amounts of sea level rise might be only the beginning if business-as-usual continues just a little bit more. If Malmö and Cape Town were transformed into postcards of the egalitarian city, with rights to water and protection against it secured for everyone, there would still come a point when floods and drought would make them unliveable. Eating and drinking the rich might be all well and good, but after that meal, there will have to be nourishment from nature for life to go on, unless liberation is to be some kind of last supper – another way to say that discontent over adaptation must ultimately leap over to the field of mitigation.

In the summer of 2021, the province of Khuzestan briefly made headlines outside of Iran, when crowds thronged the streets and chanted 'I am thirsty!'[14] Police and *basij* forces responded with the standard fare of repression, shutting down the internet and killing at least eight people – a water war far bloodier than that in Sainte-Soline; perhaps the most intense climate-induced uprising anywhere in the early 2020s. The background was indicative of the times. The summer of 2021 was the driest in Iran in at least half a century, precipitation having fallen to 15 per cent of the average in the south-west. As temperatures hovered around fifty degrees, the rivers nourishing Khuzestan dried out, leaving fields baked, water buffaloes dying and potable water in even shorter supply than usual.[15] Popular patience snapped. The revolt targeted the Islamic Republic and its utter inability to secure basic access to water for the people of Khuzestan: but it did not target its complete reliance on profits from fossil fuels. The National Iranian Oil Company was one of the world's top contributors to global warming

around this time.[16] Like all others in that business, it was dead set on expanding its facilities – fields, platforms, refineries – even further, most of which happened to be located in Khuzestan itself, the original cradle of oil in the Middle East. Success in that pursuit would mean an even more comprehensive desiccation of the province (as well as other regions of the world perched on the brink of aridity, of course). Conversely, had the people of Khuzestan succeeded in remodelling water distribution but not in freeing Iran from fossil fuel extraction, it would have been a half victory, at most. But once the dead lay buried, it was clear that they had succeeded in neither.

A similar episode played out in Spain in late 2024, after a deluge hit the city of Valencia: fuelled by hot oceans and a turbocharged hydrological cycle, it killed some 230 people, gutted houses and collected carcasses of cars in thick piles across the city.[17] Rage flared in its wake. Authorities were blamed for the death and devastation. The first decision by the alliance of the right and far right after it came into power in the region of Valencia in 2023 was to close down an emergency response unit, formed by the previous red–green coalition to coordinate relief efforts in the event of a flood or heatwave or some other extreme weather event: the denialists in charge considered it a waste of money. On the day of the deluge, flood alerts were broadcast too late. Popular anger thus took aim at figures of the Spanish state: upon entering the disaster zone, the king and queen were pelted and smeared with mud, the prime minister struck with a stick.[18] A fortnight after the downpours, some 100,000 people marched through the streets of Valencia and vented their frustration at the right-wing regional president, chanting, ‘You killed us’ and ‘We are stained with mud, you are stained with blood.’[19] The city hall received the mud treatment, alongside chairs and other projectiles. The most enraged bloc of demonstrators surrounded policemen and fought pitched if brief battles. Here was the first climate riot in the global North, in the sense of fossil fuel combustion causing an extreme weather event directly precipitating confrontations in the streets.[20]

What no one in Valencia or elsewhere in Spain thought to target, however, was Repsol. The Spanish avatar of primitive fossil capital, it ranked fifty on the list of the companies that have brought the most fossil fuels to the surface over the past two centuries; like its competitors, it would not quit this spiral.[21] Months before the Valencia deluge, Repsol secured the rights to ‘continue and expand its oil and gas business in Venezuela’ – just

another day of bringing fuel to the fire.[22] The company gave the typical priority to investing in the lucrative stock rather than the lacklustre flow.[23] But neither the demonstrators in the streets nor the socialists in the national government seemed to connect the dots. As for the former, there seemed to be a danger of myopia, however legitimate the revulsion against authorities making a bad climate worse; in a subaltern version of the doom loop, people might train their eyes on the nearest politician and forget the fossil capitalist. As for the government, it sent thousands of soldiers to assist flood victims – the country's largest ever peacetime deployment of troops – and followed up with an unusual reform: up to four days of 'paid climate leave' for workers, so as to protect them against the hazards of travelling and working during extreme weather.[24] That might count as an instance of transformational adaptation. It also raised the question of how many days of payment a socialist government would be prepared to shoulder if Repsol and its likes remained untouchable.

'Transformational adaptation' clearly has greater potentials to provide meaningful protection to the masses than banking on muscular tech. Yet it too has its limits. In the longer term, every type of adaptation to unmitigated warming will be like staying on the same spot on a constantly accelerating treadmill. The two phenomena could also be viewed as intrinsically coupled, however: if warming is unmitigated, adaptation is likely to be of the most deficient kind, since each expresses the same underlying balance of class forces. And vice versa: revolutionary adaptation could march arm in arm with the long overdue assault on fossil capital. Because the overshoot conjuncture is a monument to the victories of the dominant classes, transformational adaptation mostly remained a nice idea in the early 2020s – a programme sketched by progressive intellectuals and attempted by grassroot actors too weak, as yet, to make a real difference (with rare exceptions). A survey of the global landscape of adaptation found almost no evidence for transformational efforts. Rather, people around the world would scrape by to the best of their abilities: move from their homes, change livestock species, eat differently, try to guard their plots from encroaching salinity.[25] Such spontaneous coping strategies amounted to a run through the battlefield, the default logic of the survival of the socially fittest. And in the early 2020s, the next frontier of adaptation moved further away from any change in human relations, to even more muscular tech: sea walls around the poles.

5

Bring out the Snow Cannons

If the seas keep rising, the waves will lap higher onto every shore on the planet, from Barbados to Bangladesh. But what if the map could be flipped around? Rather than dealing with the water when it arrives at its far-flung destinations, one could bottle it up in the ice sheets. Instead of having to deal with tens of thousands of zones of adaptation, the problem might be narrowed down to a few choke points. This was the rationale behind a proposal to build sea walls around the poles, published in *Nature* in 2018: 'Should we spend vast sums to wall off the world's coasts, or can we address the problem at its source?' – rather audacious phrasing, given that the point of this fix would, again, be precisely to not address the problem at its source.[1] But in a geophysical manner of speaking, streams of ice heading towards the outlets of Greenland and Antarctica do function as 'sources' of sea level rise. Led by John Moore of Lapland University, in the far north of Finland, this team of researchers thus suggested that the most important stream on Greenland be locked up behind a concrete wall 100 metres high and 5 kilometres long. Glaciers on Antarctica could be held back by networks of berms and artificial islands.[2] But these were only the first in a string of proposals. When it comes to keeping something unpleasant tucked away, the imagination of engineers is rarely constrained.

The warming water of the oceans washes against the ice sheets and breaks them up. Hence, Moore argued, one could build 'curtains' anchored on the seafloor – a kind of undulating wall moving against the currents – to deflect the heat from sensitive spots.[3] He hoped to have the first experimental prototypes installed in front of a Norwegian fjord by 2026.[4]

He told the *New York Times* he was ‘superoptimistic’ about the project.[5] Or, one could position snow cannons all around Antarctica to shoot more material into the ice.[6] Or, one could cover melting ponds with glass bubbles; or stabilise glaciers by injecting cold liquids (such as liquified CO_2) into their bottoms; or drill into them to extract meltwater and return it to the surface where it would refreeze – by the early 2020s, a smorgasbord of options had been laid out.[7] Some also applied to the Arctic sea ice. One team advocated the establishment of a forest of wind turbines around the Arctic for driving pumps for lifting and spraying seawater on the ice in wintertime, so it would thicken before the melting in summer.[8] Because overshoot was now a fact, ‘ice volcanoes’ had to be constructed, another team chimed in.[9] In 2024, the first experiments in such refreezing techniques were undertaken, by researchers and, not to be forgotten, private startups.[10]

This is muscular adaptationism outsourced to the antipodes and shading into geoengineering, even if it doesn’t aim at the energy balance of the planet as a whole. It presents formidable engineering challenges. Antarctica is the continent least covered in infrastructure; damming up its ice flow would require technological colonisation nearly from scratch.[11] Greenland would only be slightly easier to master. To build a forest of wind-powered pumps for preserving the Arctic ice sheet, there would, the friends of this idea calculated, have to be 100 million devices manufactured, transported and erected over a ten-year period, consuming more than the annual output of steel from the US and nearly three times total global shipping capacity.[12] But this could be sold as a stimulus package. The pump forest would be ‘an enterprise comparable in scope to the US automotive industry, or the execution of the Iraq War’, meaning that ‘this money, largely spent on manufacturing, would stimulate the economy and encourage economic growth’.[13] Presumably, this growth would involve some fossil fuels. Reviving Ausubel’s continuationist theory, some of the proposals were modelled on how the oil industry has installed its platforms in even the most extreme marine environments.[14]

Would any of this work? Like the sea walls outside the resort towns of northern Egypt, any barrier in front of an ice sheet would merely divert mass and energy elsewhere, as per the laws of physics. Some might increase the pressure on other glaciers.[15] If these grow thicker, however, the speed

by which they flow towards the coastlines will also increase, just like a heavier person will slide quicker down a water chute – any fattening exercise could be counterproductive.[16] Ice formed from pumped-up saltwater will melt faster in summertime than that from fresh precipitation.[17] It could cause shelves to fracture.[18] Preservation of the ice sheets would in and of themselves fail to bend the curve of warming; accelerating melting would simply increase the amount of ice that would need to be made every year: a Sisyphean labour of pushing against the global trends.[19]

But if these technologies would be deployed on the polar fronts, and if they were to give an initial impression of efficiency – if they appeared to work, in short – chances are that one key aspect of the climate problem would seem to be under control. The incentive to mitigate could then be further dulled. Indeed, one cannot rule out that such substitution began to do its stealthy work already in the early 2020s, when reports of glacial engineering technologies began to circulate. Lastly, if any of them were ever to be implemented, they would multiply the fronts of climate politics. What would the Greenlanders think of 'building dams in fjords for the benefit of the rich West'?[20] If the fates of low-lying lands across the planet were tied to a few centralised dams in Antarctica – *mégabassines* for the sea ice – how would any conflict of interests play out between them and the *terra nullius*? Who would carve up the last continent to ensure the proper 'governance' of the tech?[21] How would it happen? By raising such open-ended questions, glacial engineering technologies partook of the general structure of climate politics when it's too late. In the early overshoot conjuncture, there is no end to the technologies that can be dreamed up for managing what has not been resolved. And all set new spirals in motion.

PART II

Negative Emissions Are (Mostly) Negative Magic

6

Lamps over the Rainforest

In 2022, six scientists took to the pages of a well-respected journal to unveil a fresh solution to the climate problem. They began with the routine observation that ‘despite the scientific consensus on climate change, emission reduction efforts have made slow or little progress, with global greenhouse gas emissions continuing to rise’.[1] Hence we must try something else. How about hanging lamps over the rainforests? Plants capture CO_2 when they grow. For this, they need sunlight. There are lots of plants in tropical forests. But sunlight is constrained by nightfall – so why not lift this barrier and extinguish the darkness and bathe the tropical forests of the earth in round-the-clock light, so they can draw down all the CO_2 one could wish for? The scientists proposed a grid of lamps above the canopies shining into the vegetation through the night. This would keep photosynthesis going regardless of the diurnal cycle. The computer models, in which the team conducted the experiment, suggested that tropical forests would absorb fifteen times more CO_2 if illuminated in this fashion – so much carbon sequestered in leaves, branches, trunks and, ultimately, as the plants shed their litter, the soil. The atmospheric concentration of CO_2 would consequently fall. Indeed, ‘lighting up Amazonian tropical forests alone could completely offset anthropogenic carbon emissions.’[2] Eureka! We may not be able to reduce emissions, but we can undo all of them by hanging lamps over the Amazon.

The scientists did not explain how exactly to go about constructing the installations. But towards the end of their article, they did take brief notice of one snag. The ecosystems of tropical rainforests are used to nightfall. In

fact, they have evolved with the diurnal cycle as a given. Plants, mammals, birds, every living thing has adapted to the rotation of the earth around its axis and the ensuing variations in solar radiation: how would a jaguar react to strobes suddenly lighting up its den? How would the bamboo respond? Or the majestic, fast-growing Capirona tree native to the Amazon, one of the species on which the removal of CO_2 would hinge? Over three short sentences, the scientists acknowledged that tropical forests house a great deal of biodiversity, 'with organisms and interactions occurring in the darkness. An extension of photoperiods' – artificially prolonged days – 'could disrupt' those forests, a disruption the gravity of which would be anybody's guess.[3] But the authors were not by this disheartened. 'Given the potentially inverse relationship between more light at night and ecosystem health' – that is, the more you drench the forests in light, the sicker they become – it would be up to 'policy makers' to manage the system rationally and optimally. They would have to calibrate the nightlight at exactly the level where carbon sequestration is maximised. They would be tasked with 'protecting local biodiversity from disastrous impacts' – in plainer terms: a collapse of these ecosystems – and making sure consequences on the ground, in the dens and groves, are 'rigorously evaluated'.[4] If only they did this, it could all work out fine.

In its ostensible creativity, the idea of lamps over the rainforest is typical for overshoot ideology. Fossil capital is postulated as an unassailable background condition. Therefore, something else must be assailed – in this case, the alternation of day and night in tropical forests. Deference to the political status quo translates into reckless experimentation with ecosystems or indeed an entire biome; because the former is unbreakable, the latter must be broken. Conservatism or fatalism about society flips into extreme adventurism about nature. Also characteristic of overshoot ideology, however, is the insertion of a rationalist-optimist article of faith: any dangers of side effects can be avoided by the agents in charge perfecting the tech. The 'policy makers' must be entrusted with running the compensatory systems with prudence. One can here, if nothing else, scent the potential for a further multiplication of secondary fronts. One can imagine the struggles that would break out in and around the remaining tropical forests, were some companies or states to start hanging lamps over their canopies and switching them on when dusk sets. How would the people living in and off

those forests react? It might not take much effort to sabotage a network of dangling light bulbs.

As of this writing, no one has initiated the installation process. We are aware of no startups in the business of perpetual sylvan days. The call from the six scientists to complement their simulations with ‘ecosystem-level field experiments’ has, as of the mid-2020s, yet to be heeded. But the world is awash in other technologies for removing CO_2 from the air.[5] There is a superfluity of schemes for performing the trick, each with its own emerging ecosystem of startups and established enterprises. There is no shortage of ideas for how humans can break into the forests and oceans and rocks and soil and air to take down CO_2 from the atmosphere: and each has its own set of potentials for spiralling conflicts and collateral damages. We shall inspect a catalogue of techs in various stages of development. All are united by the primary problem that holds this front of climate politics together: if there are technologies for carbon dioxide removal, what are we going to do with them? What purpose should they serve? In whose interest will they be deployed, to what ultimate ends?

Stop and reverse

There is already far too much CO_2 in the atmosphere. There has been too much of it for quite some time, and the longer business-as-usual continues, the greater the excess will be. Wherever exactly one draws the line for when it is ‘too late’, the meaning of it is invariably this: *too much* of the principal gas is coating the planet. But from this also follows the possibility of a time warp. If a way can be found to remove CO_2 from the atmosphere, the too-lateness might be annulled and the climate returned to some prior state, before the disasters.

The notion glows with appeal. It opens up horizons for climates beyond the dismal present and future. In its absence, the best-case scenario would be a stagnating degree of misery. If all emissions were to be terminated in this moment, we and the generations coming after us would still be condemned to living out our days under skies laden with carbon. Because CO_2 is a long-lived gas accumulating over time, every new ton piled on top

of the previous one, the legacy of the fossil economy would be destined to hang like a cesspool over our heads for millennia to come.[6] Cutting emissions to zero would stop the additions, but it would do nothing to alleviate the damage already done. Turn off the economy tomorrow and the CO_2 concentration and eo ipso average temperature would cease to rise: but decline they would not. The thermostat would remain stuck at 1.2°C, if the switch-off would happen in 2022; perhaps at 1.6°C, if in 2027.[7]

But if CO_2 can be piped out of the atmosphere and returned to the solid Earth, the rules of the game change. Crossing out the legacy now becomes an option. No longer would the combustion of past generations have to weigh like a nightmare on the brains of the living. The cesspool can be drained and funnelled out of sight, into some part of the passive carbon cycle, from which the gas would not be able to escape back into the atmosphere. A more common metaphor has been that of a bathtub. The climate system is like a tub, with a faucet at the top and a drain at the bottom. Emissions come flowing like water through the tap, but because it takes thousands of years for natural processes to clean the carbon from the air, 'the drain is so slow that it is essentially clogged', as Wake Smith puts it in *Pandora's Toolbox: The Hopes and Hazards of Climate Intervention*.[8] It follows that the water level rises and rises and just keeps rising for as long as the tap is open, until the tub overflows and whoever is in it – perhaps it is a child – drowns. Cutting the flow from the tap by half would be of scant help. It would merely make the water rise at lower speed. As long as the tap is open and anything drips from it, inundation will be inevitable, and so 'we must stop it. Turn it off. All the way to zero.' But if the child already has water up to her lips then this won't be enough either. Some contraption must also be installed 'to lower the level of water in the bathtub without having to wait a couple of millennia for nature to do the job'.[9] The drain must be widened: the imperative for carbon dioxide removal.

The perception that it is or very soon will be too late inspires a search for removal. There is not much that can be done about a surplus of CO_2 other than taking it out. In a much-cited paper from 2008, James Hansen and colleagues noted that the atmospheric CO_2 concentration had already put the climate in danger of being destabilised: it then stood at 385 parts per million (ppm). In 2024, it reached just short of 427 ppm, a peak not seen in several million years, with no let-up in sight; rising by 3 ppm per annum,

the concentration grew at the fastest clip ever registered.[10] Hansen and his team famously suggested that humanity should aim to return to 350 ppm, a plateau where a climate congenial to civilisation could be maintained. To accomplish such a mission, industrial-scale technologies for capturing the gas would be necessary; they called for massive efforts in research and development.[11] Bill McKibben promptly declared 350 ‘the number every person needs to know’ and tattooed it on his climate movement 350.org, hugely influential in the years around 2010, not the least through its campaigns for divesting from fossil fuels.[12] Implicit in this number was the same quest for removal. For Hansen as for McKibben, however, the first step and absolute sine qua non would be to *stop* emissions. Only then could the warming be rolled back. Wake Smith swore himself to the same programme: turn off the tap; flush out the water – or ‘mop up the spill’, in the words of the *MIT Technology Review*. ‘Efforts to pull carbon out of the atmosphere won’t replace the need to cut emissions moving forward, but we’ve already polluted too much to neglect the cleanup.’[13]

The widely shared vision is here to *stop and reverse* the accumulation of CO_2 in the atmosphere. The world can ‘dial the clock backward’ only by doing both of these two things – on its own, one of them would be insufficient – and given how close to midnight it already is, if indeed that point has not already been reached, this is the minimum now required.[14] The challenge is to move down all the unwanted carbon and make room for it in the crevices of the earth. It would affect an annihilation of time by space.

The lure of a time machine

Technologies of carbon dioxide removal are thus bundled together in a meta-technology, the ultimate marvel: the time machine. They will make the earth travel back in time. At a get-together for entrepreneurs in the budding removal industry in the summer of 2023, Marta Krupinska narrated her own eureka moment. She had been working with Google before cofounding and becoming the CEO of Cur8, a ‘market-maker for carbon removals’.[15] What made her change career? Grabbing the microphone to

give her testimony, Krupinska recalled how, on the way to a Christmas party, a friend told her of methods for removing carbon and sequestering it in the soil: 'and it blows my mind. Because suddenly, it opens me up to this idea that, OK, hang on a second, we can accelerate natural processes and there are different ways of pulling carbon out of the sky and, hang on a second, that means we can build these *time machines*' – deep emphasis – 'and have the ability to feel hope on the climate front. And let me just say, this was better than alcohol at that Christmas party.'[16]

A few months later, the same image was invoked when the US saw the ceremonial inauguration of its first commercial facility for Direct Air Capture, or DAC, a frontline contender among the technologies, about which we shall have much to say. The CEO of the company behind it, 'Heirloom', described DAC as 'the closest thing on Earth that we have to a time machine, because it can turn back the clock on climate change'.[17] Sauntering around between pipes and storage tanks before grabbing the shears to cut the ribbon, Biden's Secretary of Energy Jennifer Granholm seemed positively enthralled: 'We have been polluting, with carbon, our atmosphere since the Industrial Revolution, and you cannot unpollute – except with this.'[18] Another startup, competing with Heirloom by advancing a different version of DAC and drawing on money from Google, called itself '280.earth', 280 indicating the atmospheric CO_2 concentration to which these entrepreneurs wished to take the planet back; 'reversing the clock on climate change' was their slogan.[19] One writer in *Washington Quarterly* dubbed DAC a 'carbon time machine. It can erase past emissions and turn back the clock. Tock tick', while one writer in *Bloomberg* assembled all the different removal techs into 'a time machine that can take us back to an ideal state, say about 275 years to the pre-industrial era'.[20] By the early 2020s, one fraction of the American bourgeoisie was amped-up for the prospect of building this machine, and with the Biden administration pouring money into it, the endeavour had the imprimatur of the highest office.

Not all conceptualisations of removal explicitly referenced the magic of time travel. The key point could be made without it. Climeworks, a pioneering DAC company based in Switzerland, originally adopted a brazen enough motto: 'Let's reverse climate change'.[21] The tellingly entitled Global Thermostat – for some time the main US competitor of Climeworks

– had two eccentric cofounders in the characters Graciela Chichilnisky and Peter Eisenberger: they had taken on ‘the mission of reversing climate change while making profits’.[22] Climate-tech investor firm Lower Carbon Capital was cool enough to declare that it ‘backs kickass companies that make real money’ by ‘sucking carbon out of the sky, and buying us time to unf**k the planet’, the latter three words its own unique slogan.[23] Another company in the business of enhanced weathering, a technology to which we shall also return, called itself UNDO and announced, ‘We’re here to undo the damage done’.[24] Unfucked, undone: the underlying premise in all of this was that global warming can in fact be reversed like an unspooled roll of toilet paper returned to its original packaging. Discussions of removal thus continuously referred to the notion of ‘reversing’ the process that could not be avoided.[25]

How far back in time? 350 ppm meant aiming for the mid-1980s, when that concentration was last seen in the atmosphere; but there would seem to be no reason to stop there. The world could, as *Bloomberg* intimated, go all the way back to the climatic Eden reigning before the rise of the steam engine. (Or further back still: one study identified the baseline as the year 850 AD, when the Carolingian Empire started razing the forests of Europe. Removal should also do away with the CO_2 emitted from deforestation and so bring us back to pre-Carolingian times.)[26] Such ambitions were often filed under the label ‘climate restoration’. Among the vocal proponents was astrophysicist and self-identified ‘serial entrepreneur’ – the good twin of the serial killer, perhaps – Peter Fiekowsky, who stamped a foundation out of the ground to advocate for its necessity: he considered the Paris goals insufficient to guarantee ‘the survival of human society as we know it or even that of homo sapiens as a species’.[27] Only the full reversal of global temperatures to their Holocene state would cut it. This, he believed, could easily be achieved by 2050, as the capacity for removal would hit 50 gigatonnes of CO_2 every year – 10 more than the world economy emitted in the early 2020s – well before that date, the atmosphere successively emptied of the post-steam sum total.[28] We will have reason to place question marks around this notion later.

Restoration could also be associated less with juice and more with justice. A US youth group called Worldward rallied behind the idea and published a letter in the *Guardian* on the need ‘to go beyond net zero, and

start to restore the climate' to 'as close to a safe climate as possible'. It was endorsed by Hansen, George Monbiot, Michael Mann, Mark Lynas and other heavy hitters of the climate cause.[29] Others talked of 'climate repair' or 'climate reparations', linking the emerging techs to ideals of compensation for historical wrongs.[30] Rich countries ought to clean up the mess they have poured over the heads of the poor. It would be a decent way for them to repay their debts.[31] For progressives of this bent, the promise of removal lay in a double movement of stop-and-reverse. Some, however, read the promise in subtly but significantly different terms.

Continue and reverse later

When, in the early twenty-first century, modellers, governments, summits, companies and other agents prepared for overshoot, the tap was nowhere near closing. It rather discharged more effluents for every year that passed. And when defenders of the status quo now factored in removal, they did so for a particular purpose: to mop up spills still in the future. Emissions could continue for a good while longer, because these technologies promised to take care of them at a later date. This was something different from what a Hansen or a McKibben had in mind: an excuse to prolong business-as-usual even further. Instead of a contingency plan for an urgent shutdown of fossil fuel infrastructure combined with massive drawdown of CO_2, it was rather the opposite: dreaming up the latter so as to avoid having to do the former. The makers of overshoot threw their hands up at the wide-open tap and counted on devices for channelling away the glut that must first be released. Turning off the tap *now* was out of the question. In the second half of the century, a fully automated, yet-to-be-developed mopping machine would sweep up the overflow and take it out of the building.[32]

Next to the vision of stop-and-reverse, then, we have a rival configuration: *continue* the accumulation of CO_2 and reverse it at a later date. This is the logic of overshoot-and-return, or 'temporary' overshoot. It is related to the idea that lamps dangling over the rainforest could sustain and cover up for the failure, or refusal, to bring emissions under control. Plenty of objections could be raised. One concerns the very premise that global heating possesses the property of reversibility. As soon as the idea of

overshoot had entered the scientific literature, papers started backing it up with modelling that supposedly proved the existence of this property: if CO_2 reaches 750 ppm in the early 2100s, it can be brought down to 630 in 2300, and then key parameters – temperature, carbon fluxes, circulations in the oceans – would indeed be returned to their starting positions.[33] Overshoot-and-return hinged on this being true. But it can be questioned.

Is it safe to expect to dial temperatures up and down, as on a thermostat? Are the damages of such a kind that they can be undone *ex post facto*? Is this any more in the hands of humans than resurrection, the other archetypal story of a curve in time? If the answers are negative, banking on removal technologies to unleash overshoot would be reckless in the extreme. But it would pose constraints for repair and restoration too. The question of whether a climate system undergoing breakdown is in fact marked by reversibility represents the weak point for any vision of reversal. It is to this question we must turn first, before others can be answered.

7

Breaks in the Time Machine

Turn a thermostat up and the apartment gets warmer; turn it down and it cools. Mechanical devices tend to work this way. An input generates a proportional output, allowing the owner to regulate the yield, whether it be heating from a thermostat, water from a tap, speed from an engine or electricity from the turbines of a dam. At the most general level, the climate system seems to obey similar laws. Central to all climate science is the early insight that atmospheric concentrations of CO_2 affect average surface temperature in a relationship of (so it appears) near perfect linearity. One amount of the gas poured into the sky causes one quantity of warming on Earth: release a plume of 100 gigatonnes and you can be reasonably sure about how much heat is realised down below. Double the emissions and you double the attendant heat.

The warming can be avoided no more than excretion after digestion, and it is this relationship – tight and linear, at first glance – that enables scientists to predict roughly how high temperatures will be pushed by a certain quantum of emissions in the coming decades.[1] It also lends itself to the notion of reversal. If a quantum of CO_2 is *subtracted*, the outcome will *ceteris paribus* be a corresponding cooling. 100 gigatonnes dispersed into the atmosphere trap a given amount of solar energy; deduct as much and the same amount will slip back into space; take away more and still more heat will seep out from Earth, and so on – just as a bathtub can be filled and emptied, so this system can be subjected to the basics of arithmetic.

All emissions, it would then seem to follow, are equal. In the exchange over the decades and centuries, the currency of CO_2 is fixed at the same

value, one coin on the plus side matched by one on the minus. It does not matter when the transaction takes place. One quantum of the gas withdrawn from the atmosphere after the world hits 1.5°C has a causal power identical to the same quantum deposited; positive emissions can be cancelled out by later ‘negative emissions’ – another term for carbon dioxide removal, much in vogue during the 2010s. It was thanks to this symmetry that programmatic overshoot could enter the models. The world may well permit itself to exceed 1.5°C or 2°C, because it can reverse course and go back to the appropriate limit by means of negative emissions technologies, and nothing untoward will have happened in the interim. Overshooting and returning would be very nearly the same thing as never having transgressed the limit in the first place.

In relation to the material base, as we have already seen, such programmatic overshoot performed the work of capital protection. It shielded assets against the destruction required if the limit of 1.5°C (to begin with) were to be actually respected. By distending the schedule for hitting that target, it offered to save fossil capital from impending death and give it an unspecified number of more decades to self-expand.[2] But at the level of the superstructure, overshoot had another, related, fateful source: the view of nature as a machine.

Earth the machine

Mechanist worldviews, too, have a plurality of sources, but in modern Western science, an especially important wellspring has been the discipline of geology. The man known as its father, John Hutton, set out to decode the earth as a machine. His modestly entitled manifesto ‘Theory of the Earth’ opened with the following sentence: ‘When we trace the parts of which this terrestrial system is composed, and when we view the general connection of those several parts, *the whole presents a machine of a peculiar construction* by which it is adapted to a certain end,’ this end being the best possible world for humans to live in.[3] Hutton proceeded to show that atmosphere and gravitation are pulleys and levers; light and heat, cold and condensation, winds and tides and currents are gears in one giant, well-oiled machine. Formations visible to the eye – mountains and beaches, rivers and

lakes – have resulted from the earth ticking away over unfathomably long periods of time.[4] ('Fossil coal' is another product.)[5] Time is a deep vessel. It is also neutral and hollow, because the earth abides by unchanging mechanical principles. Erosion, deposition, consolidation, uplift form and reform the planet today just as they did aeons ago and will aeons hence; 'the operations of nature are equal and steady', and thus time 'is to nature endless and as nothing'.[6] It leaves no more trace on the workings of this machine than an hour does on a clock.

If something goes wrong, the earth will set it straight. Hutton decorated his theory with concepts of 'repair' and 'renovation': if rock is worn away by river and rain, debris will amass in the ocean beds, layer upon layer, until new strata arise. Any 'decay of the machine is naturally repaired', any 'ruined constitution' restored; 'the destruction of one continent is not brought about without the renovation of the earth in the production of another.'[7] The earth-machine is defined by reversibility. Time is here cyclical, a loop of recurrences that can see no permanent alterations or directional change – above all, no catastrophes with lasting effects.[8] 'No latent seeds of evil threaten destruction of the whole,' one follower of Hutton summed up his doctrine.[9] The machine, in short, knows no history.

It was not a coincidence that 'Theory of the Earth' appeared in the same year – 1788 – that James Watt patented the centrifugal governor, the cherry on top of his steam engine, ensuring that it rotated at constant speed. Hutton was a companion of Watt. Adoringly, Hutton wrote to Watt, 'I admire so much your reciprocating engine'; in return, Watt read 'Theory' and told the author, 'I see much to commend & admire.' The inventor thought it possible 'to prove some parts of it by experiment though not all – I cannot pretend to find fires to melt marbles & flints, *but I can to melt coals*.'[10] The mechanist worldview was forged in the same northern British workshop as the steam engine: an ideology made for fossil capital. The alternative school of geology emanating from the French Revolution, the catastrophism of George Cuvier, who posited that floods and other cataclysmic events had wiped out species and scarred the planet for good, was purged from the young science as wholly inappropriate.[11]

The British theory of the earth was instead further codified by Charles Lyell. His main contribution was to harden the doctrine of gradualism. He believed in 'the tranquil deposition of sedimentary matter and the slow

development of organic life': things happen increment by increment, each as minute as the last, lining up in a sequence that takes time to reach its full effect.[12] One raindrop leaves no imprint on a plain. But if billions of drops fall on the same spot – identical factors marching in sufficiently long succession – they might gouge out a valley. The crust rises into mountain chains at a pace so stately that it cannot be observed. Causality is linear: cause x in a small amount triggers effect y of the same small amount, a slightly larger X a proportionally larger Y; but the rule is smallness. The earth and all things on it have moved and move and will continue to move at a rhythm of step after tiny step: 'There has never been any interruption to the same uniform order of physical events.'[13] Any paroxysms in the past – floods, earthquakes, volcanic eruptions – were local and of trifling consequence. Balance was always restored. The earth counterposes elevation to subsidence and birth to death, evening out the sum of land and life: in Lyell's geology, the planet 'does double entry book-keeping'.[14] What damages could humans wreak on such a construction? None, essentially. If humankind were to disappear from the earth, its footprints in the sand would be soon erased. In the words of one historian of science, Lyell's was a theory of 'non-time, things not changing over time': time 'effectively annihilated'.[15]

If this sounds suspiciously similar to the image of a factory hall with automated machinery in good and undisturbed order, it is, again, not a coincidence.[16] Lyell was a companion of Charles Babbage, known as the father of the computer. His 'difference engine' was designed to perform complex mathematical calculations; never built in his own days, it bequeathed a sort of blueprint for digital technology. It represented a distillation of the factory system as keenly observed by Babbage, the division of labour into minimal, mechanical operations to be replicated inside his proto-computer. Lyell saw in it a mirror of the earth. The environment of the future would fall into the right slots, just as easily as it was 'for Babbage to find what would be the place of every wheel in his new calculating machine'.[17] As for revolution or catastrophe, perish the thought; these men envisioned stable and predictable outcomes. Humans have discovered 'few signs of a beginning – no symptom of an end' – a line Babbage adapted from Hutton.[18] Time was voided of concrete content and formalised into an abstraction: but the formula of abstract time had a

concrete basis in the steam engine. Only a prime mover indifferent to swings in the weather could make it appear a credible proposition for how the physical world works.[19] Lyell and Babbage wrote their main treatises in the early 1830s, just as British industry tipped from water power to steam; both saw a formal correspondence between the reciprocating and calculating engines and the planetary automaton.[20]

We may then propose the following. In their most prominent guises, carbon dioxide removal and geoengineering represent attempts to resuscitate the ideology of the earth-machine – first minted in the birthplace of fossil capital – *after the event of the climate catastrophe*. But they do more than dust off the old theory of the earth and give it a new sheen. They also aim to *implement* it. The point is no longer to postulate that the earth mimics a machine, but to envelop it in actual machines – the various techs for removal and geoengineering – that *make it behave as one*. The vision is for the planet to realise some essential properties of a machine: linearity, reversibility, controllability; a device that one can play and rewind. We shall see what concrete forms this project takes. For now, though, we must stress that this cannot be a damning verdict on removal or geoengineering in and of itself. It might still be the case that the models are accurate and the technologies worthy of adoption. Evidence will have to adjudicate.[21]

As steam power ascended to world domination during the mid-nineteenth century, gradualism developed into something like a scientific meta-paradigm.[22] The scientist most responsible for this was a third Charles, surname Darwin. He held that variations among organisms had to be ‘infinitesimally small’ for natural selection to do its work. If they appeared in concentrated bursts, an organ or a species emerging complete from one moment to the next, selective pressure would be causally impotent in evolution: variation itself would be the creative force. ‘As modern geology has almost banished such views as the excavation of a great valley by a single diluvial wave, so will natural selection, if it be a true principle, banish the belief’ in any form of saltation, any ‘great and sudden modification’ in the structure of living beings.[23] Zealously devoted to gradualism, Darwin took as his credo *natura non facit saltum*, ‘nature makes no leaps’. Nature operates through miniscule, successive, on the whole favourable alterations.[24]

But there was for this theory, as for Lyell's gradualism, one pesky little problem: the evidence. As they lay spread out around the feet of these naturalists, the facts spoke another language. The fossil record did not bear out fine gradations between organs or species. It rather suggested ruptures: fully formed taxa appearing out of whole cloth and staying the same for millions of years until they just as suddenly vanished again. To take but one example, Cuvier had pointed to three species of elephant, the African, the Indian and the mammoth, branching out from the ancestral genus *Primelephas* at the same moment – now known to be around 4 million years ago – and barely undergoing any physiological change since then.[25] Similarly abrupt transitions patterned the sediments. How did Lyell and Darwin deal with such anomalies? They declared them gaps in the record, where the intermediate links *should* have been. Because gradualism was true, the signs of spurts and breaks had to be pinned on incomplete documentation in the ground. Some pages from the story of life were simply missing.[26] While this procedure cushioned the meta-paradigm of gradualism during the most triumphalist era of capitalist industry, it was bound to be challenged by less faithful scientists.

Dialectics of disaster

During the nineteenth and twentieth centuries, there was another, oppositional way of understanding the earth, rooted in dialectics. Hegel disdained gradualism. Buried within the musings on being and essence in *Science of Logic* is a piercing rebuttal of it. Gradualness denotes a change in quantity; but quantity is merely 'a moment of measure', a magnitude the increase and decrease of which in itself tells us little. A quantity of something is of interest only because of that *something*, the quality in question. Nine hundred and ninety-nine grains of wheat have their meaning from being wheat. But quantity has a way of passing into a different quality, as in the classical paradox of the heap: if you remove one grain, the heap is there; if you remove one more, still there; but at some point, before the last grain is gone, the heap of wheat has ceased to exist. After enough hairs are plucked from a man's head, he is bald. Quantity has broken out of its bounds and pushed the quality of which it is the measure into something

recognisably other. That which exists cannot rest comfortably in a process of addition or subtraction. ‘Quantum’, in an ominous phrase from Hegel, ‘is the side from which an existence is unsuspectedly attacked and laid low.’[27]

Unlike in the elusive paradoxes of the disappearing heap and hair, however, the transformation of quantitative into qualitative change tends to be sharply demarcated in nature. Hegel’s most famous example is, rather tellingly, built on temperature. Swings in temperature do not affect objects through insensible changes. ‘Water, in cooling, does not become hard a bit at a time, as if it became first like a porridge and would then gradually harden to the consistency of ice, but is hard all at once.’ Temperature does not roll an object through a continuous spectrum of gradations:

> Water does not become just more or less warm, but passes through the states of solid, liquid, and vapor; and these different states do not occur gradually, but, on the contrary, even the otherwise merely gradual increase in temperature is interrupted and inhibited at these points: *the irruption of another state is a leap*.[28]

Hegel’s other favourite example is taken from chemistry: adding one oxygen atom to carbon monoxide creates a thing with completely different properties, namely carbon dioxide.[29] Slightly bending a concept he uses in this context, we might call the points of transition *knotenlinie*, or ‘nodal lines’.[30] When temperature falls below the nodal line of 0°C, water is flipped into ice; when it rises above, ice melts; at 100°C, water boils. One could add that, for humans, a wet-bulb temperature of 35°C marks a nodal line beyond which the body does not just turn some per cent warmer. It absolutely expires.[31] ‘*Natura non facit saltum*, as the saying goes’; but the workings of temperature indicate that ‘the alterations of being in general are not only the passing over of a magnitude into another magnitude, but the transition from the qualitative into the quantitative and contrariwise’ – ‘a becoming-other that interrupts gradualness and stands over against the preceding existence as something qualitatively other’.[32] Hegel would have been nervous about overshoot. Above the nodal line of 1.5°C or 2°C, the earth might not become just a little bit warmer, but a place different from what it once was.

Marx and Engels lapped up the idea. In *Capital*, the former pointed to carbon compounds and the transition to a capitalist mode of production as two manifestations of one law, applicable to nature and society alike –

namely, ‘the law discovered by Hegel, in his *Logic*, that at a certain point merely quantitative differences pass over by a dialectical inversion into qualitative distinctions’.[33] But it was, of course, Engels who most obsessed over this ‘law’. In the clutter of manuscripts and fragments later published as *Dialectics of Nature*, Engels identified three laws of dialectics, of which the first had indubitable primacy. ‘In nature, in a manner exactly fixed for each individual case, qualitative changes can occur only by the quantitative addition or quantitative subtraction of matter or motion (so-called energy),’ the prime examples being, again, temperature and carbon.[34] In fact, apart from the temperature-induced transitions borrowed from Hegel, Engels most often pointed to carbon and more specifically *hydrocarbon* compounds: methane (CH_4) and ethane (C_2H_6) have varying numbers of atoms, from which divergent properties follow. Engels lifted this instantiation of leaps straight from the chemistry of the just-discovered American fuel known as oil.[35] His first law came, incidentally, out of the cauldron of heat and petroleum. His second law had to do with how opposites penetrate each other and, ‘when carried to extremes’, swap place or turn one into the other. The third laid down the spiral as the general form of development – not the straight line, nor the cycle.[36] But first and foremost, dialectics was a matter of quantity-quality leaps determining how the world works.

Stalinism embalmed Marx and Engels and petrified the laws into a dogma. It gave dialectics a bad name, as a conceptual scheme imposed on matter from the outside: a pseudo-religion, not a close listening to the rhythms of nature.[37] In anglophone academia, meanwhile, the dialectical opposition continued to generate esteemed research, not the least in the discipline of biology.[38] But it failed to unseat gradualism, until the years following 1968. A starting gun was fired in 1969 by the zoologist Richard Lewontin, who then sympathised with the Black Panther Party.[39] In a highly technical paper, he sketched a theory of ecological systems moving between alternative stable states.[40] More particularly, they can shift between ‘basins of attraction’. The classic way to visualise this concept is to think of a ball passing through a landscape of deep valleys. Once it falls into one, it gets stuck in a ‘basin of attraction’. A small perturbation will perhaps make it go up the steep side a little, before it slips back into the bottom. ‘Nothing catastrophic will occur, and the difference will hardly be noticed.’ If,

however, perturbations have amassed and the ball has been pushed up to the ridge, it will sit at a ‘structurally unstable’ or ‘transient’ point – and here, because of the backstory of the ball, an ‘infinitesimal’ perturbation may be enough to send it down into the next basin. It then takes up a new position of seemingly immovable stability.[41] One can imagine, rather than an inanimate ball, a beetle waggling its legs helplessly in the air.

A more widely influential salvo was fired a couple of years later by a comrade of Lewontin’s, the palaeontologist Stephen Jay Gould. He pointed out that Darwinist orthodoxy had been a naked emperor for more than a century: in all this time, scientists had combed the grounds for fossils and still not found the expected soft transitions between species. In practically every stratigraphic column, they were sharp, one species demarcated from another like a bronze from an iron spearhead; but true to the orthodoxy, the scientists would blush and explain away their findings as yet another embarrassing imperfection of the record. This practice, Gould argued, was no longer tenable. The time had come to let the data speak – not least the data of stasis, of species exhibiting virtually no physiological change for 99 per cent of their existence, in the millions of years between their first entry and last exit. To overturn prevailing wisdom, he and his colleague Niles Eldredge proposed the theory of ‘punctuated equilibrium’. A potentially beneficial genetic mutation will normally be lost in the crowd. In a large, central, stable population, it will dissolve before becoming widespread and fixed; but if a segment is cut off from the mother herd, the novelty might win out. In an extreme habitat, a subpopulation may be pushed to the brink of survival, and because it is small and reproductively isolated, any adaptive mutations can propagate fast. The fossil record tells the truth about evolution. Organisms will look the same: until their existence is punctuated by a pulse of speciation.[42]

In the eyes of Gould, however, punctuated equilibrium explained much more than just evolution. It was ‘a general theory of change’, ‘a different view of life’.[43] Systems of whatever kind tend to resist change. They possess a degree of inertia, of internal solidity and order; they have been built up over time and developed arrangements for enduring. An initial stressor can be absorbed. Cause *x* in a small amount may have no effect at all. But if the stressors accumulate, systems might be pressed towards a critical line: and that is when significant change happens. Change is an episodic ‘event experienced by systems only when their previous stabilities

have been stretched beyond any capacity for equilibrial return, and when they must therefore undertake a rapid excursion to a new position of stability' (the intellectual debt to Lewontin here being clear).[44] Things are generally hard to change: hence change occurs seldom and swiftly. Gradualism presupposes that systems are ready to accept any input and pass it on into a smooth build-up of reform. But more typically, systems *hold back* the input for as long as possible and retain their own quality unchanged. Gradualism posits systems without defences, a world essentially empty and frictionless: punctuated equilibrium departs from systems filled up by history.

Raised by a Communist father, himself active in the radical outfit Science for the People, Gould did not hide his debts to dialectics. He linked his theory to

> the so-called dialectical laws, reformulated by Engels from Hegel's philosophy. The dialectical laws are explicitly punctuational. They speak, for example, of the 'transformation of quantity into quality'. This may sound like mumbo jumbo, but it suggests that change occurs in large leaps following a slow accumulation of stresses that a system resists until it reaches the breaking point. Heat water and eventually it boils. Oppress the workers more and more and bring on the revolution,

or, as pointed out in one article in the *Proceedings of the National Academy of Sciences of the United States of America*, using the theory of punctuated equilibrium to explain outbreaks of social unrest, the three-centuries-old Romanov dynasty was toppled in only four days in February 1917. 'Coincidentally, the Bolshevik newspaper founded by Lenin was called *Iskra*, the spark!'[45] And, indeed, punctuated equilibrium has been applied to everything from the fate of the Neanderthals to that of climate policy in the US, the evolution of stone tools and that of art.[46]

One particularly creative recasting of the theory came from a collective of physicists around Per Bak, working in a state of euphoric inspiration in laboratories and seminar rooms, mostly in Denmark, in the 1990s.[47] Their iconic model depicts a sandpile. Imagine that grains of sand are sprinkled, one after the other, over a flat surface. First they will form an even, roundish foundation. As the grains continue to be poured out from the same point, slowly but surely, a pile begins to take shape. The grains organise themselves in slopes towards a summit. The sides become steeper; the incline rises; the structure begins to resemble a pyramid. Eventually, the

pile is vulnerable to the impact of just one more grain of sand. One additional input, of the exact same size as all that have preceded it, might send sand sliding towards the surface: in the worst case, an avalanche that destroys the system.[48]

Before this fateful moment, the sandpile has reached a state of what these physicists called *self-organised criticality*. This is characterised by a precarious contradiction between the forces of order and those of destruction. More particularly, friction keeps the grains of sand tied to one another, but as the construction grows higher like the tower of Babel, gravitation worms its way into it and strives to bring it down. Friction and gravitation struggle, until the former cannot hold the latter back; the last grain makes the pile topple over. Self-organised criticality is a tension between opposites that stores up potential energy, to the point – the nodal line, with Hegel – where it is released in a disastrous cascade. Friction maintains order; without it, the grains would not stick to each other and link up into a pyramid, but slip away into an amorphous puddle. Gravitation threatens to bring the pile down, and thanks to the achievements of friction, eventually it will, when a single grain tips the balance of forces. That grain might sweep up the others and gain an unstoppable momentum that dispatches the totality to the lowest possible elevation.[49]

Linear causality has now left the building. In self-organised criticality, there is no temporal identity and therefore no proportionality between cause and effect. The effect of one grain of sand is contingent on the history of the system; depending on when the dropping happens, it can be nil or massive. The contest between opposites builds up to the point where the smallest nudge can precipitate breakdown. (Hegel intuited this dynamic, when he wrote that water ‘can persist in fluid state even at freezing temperature if it stands still, but then the least disturbance brings it to the state of solid’.)[50] Nor is there reversibility. For the individual sandpile, the catastrophe of the avalanche concludes the biography. Before it, there might be minor slides, preliminary iterations of disorder, portents of things to come; afterwards, a creator would have to start the process of dropping grains all over again to get the pile back into shape. That would be another history.

Why ‘self-organised’? The system develops through an external addition of input, the hand that drops the grains. But the contradiction between the opposing forces is internally generated and requires no orchestration. The disastrous outcome is something other than an exogenous shock: the

destruction of Hiroshima by an atomic bomb was not an instance of self-organised criticality, but so was the destruction of inner-city districts in America during the riots of the late 1960s – not an asteroid impact, but an earthquake. The second law of dialectics, to follow Engels, is here key to the first. It is the relation between opposites that structures the system. 'Things are the way they are because of the temporary balance of opposing forces,' wrote Lewontin and Richard Levins in *The Dialectical Biologist*.[51] To anticipate what is coming, we can say that things are the way they are on Earth because of the temporary balance between the opposing forces of heat gained from insolation and heat lost through radiation back to space.[52] But CO_2 has a peculiar property, absent in CO: the three atoms of the molecule vibrate in such a way that it intercepts infrared waves on the way out from the planet. The gas grabs the rays and shoots them back down.[53] If more CO_2 is consistently poured into the atmosphere, like grains sprinkled over the pile, there will be an overaccumulation of thermal energy in the biosphere. Distributed through its various subsystems, the surplus starts to contradict the existing orders. Slides of all sizes ensue. The long heat is the *process and period of climate avalanches*.[54]

In between Gould and the Danish physicists, there was Monty Python: in 1983, the troupe produced the most sublime illustration of non-linear causality, in a sketch we can now recognise as concerned with climate change.[55] A grotesquely fat man enters a posh restaurant. His name is Mr Creosote, creosote being a chemical derived, since the 1830s, mostly from coal and used for coating and preserving things like power line poles. Mr Creosote is waited on by the *maître d'hôtel*, played by John Cleese: he personifies business-as-usual. Knowing full well what is about to happen, he continues to feed the system with a surplus of energy; indeed, he takes joy in selling his dishes to Mr Creosote. The fat man starts sending out preliminary gushes of vomit over the floor. Still Cleese makes sure that every item on the menu – *moules marinières* and *pâté de foie gras*, frogs' legs and quail eggs, jugged hare, six crates of brown ale … – are placed before him. The mass of food eventually begins to strain against the cohesion of Mr Creosote's body. He has entered a state of self-organised criticality, a half-digested stew drooling from the corners of his mouth, at which point Cleese returns to the table to tempt him with 'a wafer-thin mint'. Mr Creosote declines. 'It's only wafer-thin,' Cleese insists, the

conceit in his voice a reference to linear causality, which, of course, he knows to be untrue. ‘I couldn’t eat another thing, I’m absolutely stuffed – bugger off!’ groans Mr Creosote. ‘Just … just one,’ Cleese pleads before feeding a passively accepting Mr Creosote the mint and running for cover behind a screen: and then the belly of the man expands like a hot air balloon and explodes, sending the visceral contents in torrents all over the restaurant. The guests have been in denial. They could have seen how the cleaning woman, the female worker, bore the brunt of the early vomiting. But when the catastrophe happens, they too are swept up in a generalised retching and puking. In the last scene, the *maître d’hôtel* steps up to the table and places before the monsieur ‘the cheque’, presumably the most profitable he has ever cashed in.[56]

Folk wisdom has room for similar parables. There is the boat with volatile passengers. Perturb it a little, and the boat will begin to rock on the waves. Push it harder and it might start rocking more violently, but in all likelihood will remain stable around its point of equilibrium. Some will call it resilient. But kick it once too many times, perhaps at the exact moment when a fierce gust of wind blows in the same direction, and the boat will flip over into a new position altogether, difficult to turn upright again, perhaps drowning some passengers in the process. Ordinary language knows of similar conceptions: there is ‘the straw that broke the camel’s back’, ‘pushed to the edge’, ‘hanging by a thread’, ‘standing on the verge of getting it on’. Orgasm is the addition of one more perturbation of the same quantity that causes a qualitative leap in the system. ‘Every *birth* and every *death*, far from being a protracted gradualness, is rather its breaking off and a leap from quantitative into qualitative alteration.’[57] Engels added the example of hangover.[58] He, Hegel, Marx, Gould, the Danish physicists and others have made a convincing case that non-linear change is ubiquitous, more of a rule than an exception, wherever systems develop over time – wherever, in other words, there is history. (Although they have all been prone to the temptation of universalising their models and ‘laws’ in a sort of counter-hubris to gradualism, as in, for example, *How Nature Works*, the title of Bak’s magnum opus. Not everything always behaves like the sandpile.)

From the 1970s onwards, the meta-paradigm of gradualism in natural sciences was thrown into terminal crisis.[59] The theories of alternative stable states and punctuated equilibrium and self-organised criticality were

flanked by ‘phase transitions’, ‘bifurcation points’, ‘regime shifts’ and a host of similar concepts, besieging gradualism and the mechanist worldview more generally from all sides.[60] They formed a family of theories, an ensemble of variations on the same theme, first established by Hegel. A synthetic mix of their contributions seems permissible. All converge on a crucial addendum. When a system enters a new basin of attraction, it may exhibit what is known as ‘hysteresis’. It will not easily budge, even if the variable that pushed it over the ridge returns to its original value. It might require a far stronger lifting force to get it out again. Hysteresis is a measure of unresponsiveness to the abatement of the initial forcing, the degree to which stability defeats the reduced pressure. This is the consumed wheat heap, the bald man, the ball in the valley, the beetle on its back, the extinct species, the collapsed sandpile, the exploded Mr Creosote. ‘From a practical point of view, hysteresis is important, as it implies that this kind of catastrophic transition is not so easy to reverse.’[61]

The age of avalanches

How did this crisis play out in the field of climatology? Gradualism is the original sin of climate science. In 1896, Svante Arrhenius first calculated how the fluctuating atmospheric concentration of CO_2 drives temperatures up and down and demonstrated that it functions as the control knob of the climate system, switching the ice ages on and off.[62] Cognisant of the chemical effects of fossil fuel combustion, he also realised that the world was in for a warming; but this lay far into the future. Some nevertheless paid advance attention. In the heart of the coal country of Alabama, a newspaper published a notice in 1902 headlined ‘Hint to Coal Consumers’. It read: ‘A Swedish professor, Svante Arrhenius, has evolved a new theory of the extinction of the human race. He holds that the combustion of coal by civilised man is gradually warming the atmosphere so that in the course of a few cycles of 10,000 years the earth will be baked in a temperature close to the boiling point.’[63] This was not exactly what Arrhenius claimed, but the practically infinite time horizons were conventional wisdom.[64] Before the 1970s, ‘when climate scientists spoke of “rapid” change they had meant something happening in as little as a thousand years.’ Most considered it

‘pure speculation that the world’s entire climate could change’ in less than that.[65] In 1976, the director general of the UK Meteorological Office pondered the theory of an enhanced greenhouse effect and saw ‘no need for panic’ – ‘the climatic system is so robust, and contains so much inherent stability through the presence of negative feedback mechanisms, that man still has a long way to go before his influence becomes great enough to cause serious disruption’.[66] The discovery of global warming ran up against the wall of gradualism. It was breached only by a mass of evidence that eventually became uncontainable.[67]

A major crack was caused by the accruing data from the past, not least the glacial cycles that so fascinated Arrhenius. They upended climate in the geological blinks of an eye. The last ice age endured in a stable state for about 100,000 years, but the passage to the interglacial epoch known as the Holocene took about 3 per cent of that time; most of the restructuring of the world’s biota – the advance of forests towards the north pole, the dying out of mammals thriving on the frozen plains – was completed in little more than a millennium.[68] A minuscular variation in incoming sunlight prompted this epochal shift. As the orbit of the earth became just a little more oblique in shape, it received a dollop of extra heat from the sun – not enough on its own to account for the consequences.[69] It was, as Arrhenius showed, rather the CO_2 that set the globe rolling into a long summer. Warm water holds less of the gas than cold, as evidenced when the fizz departs a can of soda opened on a clammy day. The slightly stronger sun made the oceans unlock their stores of CO_2, which rose into the atmosphere, which warmed the planet further, which sent more fizz leaking into the air, and so on: a ‘positive feedback mechanism’ amplifying the initial push into a change far beyond it in size and scope. Once insolation had crossed a nodal line, several mechanisms of that kind coupled CO_2 and temperature in a tight embrace that sent the earth tumbling out of the ice age.[70]

Superimposed on this cycle was a series of wilder swings. From the onset of the last glacial period to its end, a total of twenty-five Dansgaard–Oeschger events – so called after their discoverers – coursed through the hemispheres: on Greenland, temperatures would spike by anywhere between 8 and 16°C *within a decade or two* before coming down again. In Europe, the jump from one decade to another would cover several degrees. Repercussions extended to the coasts of present-day Venezuela and

Morocco.[71] Now, if the climate could change so fast in the past, why not also in the near future? During the final three decades of the twentieth century, palaeoclimatologists – those who explore prehistorical climates, much like archaeologists do bygone civilisations – rammed through the wall of gradualism and made way for the conclusion that global warming – anthropogenic, this time – could in fact upend the climate within a human lifetime. But they also ran into the prejudice that this warming would *in itself* be gradual.[72] Lessons from ice cores preserved deep within the antipodes and other archives suggested that we should rather count on something akin to punctuated equilibrium.[73] Wrote prominent geoscientist Richard Alley: 'Climate can be rather stable if nothing is causing it to change, but when the climate is "pushed" or forced to change, it often jumps suddenly to very different conditions, rather than changing gradually. You might think of climate as a drunk: When left alone, it sits; when forced to move, it staggers.'[74]

The staggering can be traced in the zig-zagging trails of the deep past, passing through the mass extinction events and the planetary regimes – icehouse, coolhouse, warmhouse, hothouse – that reigned in seemingly supreme stability for tens of millions of years, until they broke.[75] And the punctuations continued in the most recent Holocene.[76] To mention only one, around 8,200 years ago, the dying ice from the glacial period slashed the world with its tail: meltwaters from the sheet previously covering much of North America had formed a giant lake. It was dammed up by icy walls. At some point, the walls caved in and collapsed. The whole lake draining at a stroke, so much cold freshwater was injected into the Atlantic as to cut temperatures by up to 5°C in Britain and Ireland within a single decade; the cooling reached the southern tip of Africa and caused droughts in the tropics.[77] The anatomy of this event has direct analogues in the present. As glaciers recede, they excrete water that often collects in basins. Walls of ice or moraine hold it in place. As more meltwater trickles down the slopes, one drop at a time, the lakes rise and fill up, remaining turquoise and deceptively still. When they reach self-organised criticality, one single knock – an influx of meltwater after a few hot summer days, or heavy rains, or ice or rock falling from a cliff and sending ripples over the surface – can cause the walls to shatter and the lakes to empty. In tsunamis the water crashes down the valleys and sweeps away everything before them.

One of the largest such events in recent history took place in September 2024, when the collected water in a remote lake in East Greenland drilled through a tunnel under the ice wall. Danish researchers – incidentally from the home institute for the theorists of self-organised criticality – observed how the water broke out and escaped in masses equalling two Niagara Falls every second. The flood continued for twenty-two days. When it finally stopped, water levels in the lake had dropped by 154 metres.[78] When such 'glacial lake outburst floods' occur in populated regions, they can bring death in the blink of an eye, as on 4 October 2023, when at least seventy people were killed and dozens of roads and bridges pulverised in the Indian province of Sikkim.[79] The Himalayas are particularly exposed to this peril. Due to the ongoing deglaciation of the Third Pole, lakes are popping up in the mountains above the peoples of the subcontinent. In one estimate, business-as-usual will create more than 13,000 lakes on the path to completely ice-free Himalayas; nearly half of growth in lake area would occur before 2050.[80] While most of the millions placed under this hazard live in the Himalayas, the Andes have so far seen an even steeper rise in the number of lakes formed.[81] From India to Peru, this is the emerging reality for inhabitants of alpine valleys: climate avalanches at any moment.

To capture this type of causality, climate scientists in the early twenty-first century picked up the concept of 'tipping points'. It entered the scholarly lexicon in the 1950s to denote the workings of American racism. Once the number of black residents in an urban neighbourhood reached a certain limit, white people could stand it no more – this was the 'tipping point' – and began to move; they left their apartments behind, which black people moved into, making the remaining whites desperate to flee, until there was a fully segregated ghetto.[82] In climate science, the term had its breakthrough moment in 2008. The timing may not have been coincidental.[83] When Lehman Brothers filed for bankruptcy, the contradictions of financialised capitalism were activated in a frightful crash; meanwhile, an article entitled 'Tipping Elements in the Earth's Climate System' – lead author Tim Lenton – aroused intense interest.[84] In the following year, Marten Scheffer published *Critical Transitions in Nature and Society*; drawing on Lewontin's alternative stable states, Gould's punctuated equilibrium, Bak's self-organised criticality and related theories, it provided analytical scaffolding to the emerging research on tipping

points.[85] Much as the crisis of gradualism was associated with the political turbulence after 1968, the rise of this concept might have been linked to the financial meltdown. Be that as it may, a pedestrian definition of the tipping point came into circulation: 'little things can make a big difference.'[86] More formally, Lenton and his colleagues specified a tipping 'element' as a subsystem of the climate system – they listed fifteen, including the permafrost, the Amazon rainforest, the Greenland and West Antarctic ice sheets – while the 'point' is where 'the future state of the system is qualitatively altered' or the line at which 'a small additional perturbation' causes 'a qualitative change'.[87] An alternative definition would be *the nodal line at which the contradiction between excess heat entering the subsystem and its hitherto existing order is so intense that an additional dose of the former (or its corollary signals) may cause the latter to break down*.

Positive feedback is sometimes included in the definition, as when the first white flight from a neighbourhood makes more whites flee, or warmer waters release CO_2.[88] The change takes on a dynamic of its own. Like an avalanche proper, it feeds itself with material and develops a runaway momentum. Confounding standard conceptions of linear causality, the moment of effect here curves back into the moment of cause and becomes one with it, and vice versa.[89] Nor is this change of a circular, rebalancing character, as in Hutton or Lyell. Rather it assumes the guise of a spiral. The tipping should therefore not be conflated with instantaneous collapse: it does not necessarily happen all at once, in a flash. Some systems take time to undergo the full response to a forcing.[90] For a while, it lives on borrowed time; it has passed on, but its bodily functions have not yet accepted the change, and so, zombie-like, it keeps stumbling forward. The *point* about the tipping is not velocity as such but the crossing of the nodal line beyond which disintegration proceeds towards a terminus – reached within a day, a decade, a century, a millennium or more – and can no longer be stopped. An essential component of the process, in other words, is *irreversibility*.[91] Once a glacial lake has burst, that unit is gone; same with the ice age, even if it took three millennia to wind down. Not even the spasm of cooling 8,200 years ago brought it back. The climate of the earth had settled into an alternative stable state, like a boulder fallen into a crater.[92]

We can then begin to discern how the phenomenon of tipping points presents a mortal threat to reversal and overshoot-and-return and the whole

assortment of related notions.[93] Carbon dioxide removal may here bite the dust. Temperatures could be brought down fairly quickly – cooling would start within a decade of CO_2 concentrations diminishing – but there is no guarantee that the impacts that *constitute climate breakdown as a material reality* would be nullified with equal facility. The glacial lakes might not reappear, let alone the glaciers that fed them. If that were even feasible, if subsystems that have passed their tipping points can possibly be returned to the status quo ante, it might take time and effort on a scale exceeding the original accumulation of CO_2. That would spoil the equivalence between a positive and a negative quantum of emissions.[94] By the same token, the existence and proximity of tipping points imply that mitigation should happen sooner rather than later – or, in plainer terms, that *capital destruction should be punctuational in character*. But when IAMs plotted a 'damage function' to represent the economic harm from global warming, tipping points were nowhere to be seen. The damage was supposed to scale smoothly with temperatures. It would progress in linear proportion to heat, rising obediently like the volume of a loudspeaker at the push of the button. On this basis, the IAMs reached the conclusion that mitigation is best postponed to the future and, moreover, that any damage done in the meantime could be undone through removal.[95] Insofar as programmatic overshoot contributed to delaying emissions cuts, it follows, *gradualism played a part in bringing on this age of avalanches*.[96]

The original sin had yet to be washed away. Not only IAMs but climate models – those that describe the natural side of the problem – remained notoriously poor at capturing tipping points. Their bias towards reproducing relatively stable climates, underrepresenting or blissfully ignoring positive feedbacks and threshold effects, had long been an open secret.[97] Tipping points would often be set aside, consigned to a folder labelled 'Less immediate concerns'. Studying them would be regarded as a chase for exotic freak events. As late as 2019, one could still read in the top journal of climate science that the impacts of this crisis 'are more likely to be intermittent, slow and gradual'.[98] Of greater authority, the IPCC, in its sixth assessment report from 2021, took note of tipping points only to bracket them out as incalculable and unmodellable surprises.[99] Such awkwardness in the face of non-linearity had plagued the Panel since its inception. The report from 1995 included a hint to 'future unexpected, large and rapid

climate system changes (as have occurred in the past)' but left the matter at that.[100] The Panel stuck to a broadly gradualist conception of how warming would unfold. This was not a recipe for realism. In the early 2010s – just as overshoot was embedded in the assessments – it became clear that the Panel had grossly underestimated key impacts already unfolding in the real world, most notably sea level rise. During the two decades around the turn of the millennium, seas rose 3.2 millimetres per year: the Panel had made projections for 2. It expected glaciers and ice sheets to meekly succumb to the heat. There would be no outbursts, or at least none that could be simulated in the models.[101]

What accounted for this mismatch between theory and evidence? One survey of the amassing discrepancies derived it from the gradualism of Lyell and Darwin: 'In the earth sciences, the tendency towards least drama has a pedigree' going back to the denial of Cuvier's floods and the fidelity to *natura non facit saltum*, challenged by Gould in the 1970s but still at work in the realm of climate.[102] The dissent of the late palaeontologist was echoed by palaeoclimatologists. Writing on sea level rise, Hansen protested against 'a tendency for "gradualism" as new evidence [was coming] to light'; 'virtually all research has relied on scenarios of slow and gradual changes', complained one team, and another scientist flushed on behalf of his guild: 'The forecast for climate change in the coming century stands in rather embarrassing contrast to the climate records of the past.'[103] If mild deviations in insolation and CO_2 had evidently set the drunkard staggering and vomiting, why would it do anything less when beaten by the full blast of ongoing emissions, a forcing of an entirely different magnitude? In the 2010s, the rise in temperature was ten times faster than during the switch from the last ice age to the Holocene.[104] The concentration of CO_2 approached levels last seen in ancient epochs: the climate was on course to relapse by 2030 to conditions resembling the Pliocene (3 million years ago), while continued business-as-usual would take it by the middle of the next century all the way back to the Eocene (50 million years ago).[105] During the Eocene, the earth was 13°C hotter than on the eve of large-scale fossil fuel combustion, meaning that 'we are effectively rewinding the climate clock by approximately 50 million years, reversing a multimillion year cooling trend in less than two centuries' – a time machine of real power.[106]

Gradualism in climate science, one might say, was itself like a zombie past its nodal line. Born as ideology in another historical era, it could still 'count as a norm' and 'exercise an eternal charm', because its articulation with the material base was *post-mortem* renewable.[107] The original precepts of the mechanist worldview aligned with Victorian ideas about bourgeois civilisation as rational and nearing perfection; and such ideas – rationalist, optimistic – have been as undying as the class that thought them up. Gradualism is axiomatically the garb of the status quo. In the IAMs and other prefigurations for overshoot, it protected against the shock of asset stranding. If the sources of its incomplete death in climate science are complex and plenty, however, the consequence is straightforward: 'Society may be lulled into a false sense of security by smooth projections of global change,' in the classic warning from Lenton and his colleagues.[108] A near equivalent would be to build a house under the moraine wall of a glacial lake. Furthermore, the house would have a pipeline pumping water into the lake above, while the warden would soothe residents with the assurance that if anything untoward were to happen, there could be reconstruction at a later date.

This is not to suggest that the tipping points of the climate system are lining up in transparent order, available for precise dating and measurement if only modellers and others removed their blinders. They are obscured by more than ideology. Their locations represent a genuine scientific problem. The nodal line for boiling water is not open to question: it has been observed countless times; everyone knows it. But just how much excess energy a subsystem of the climate can take before it gives is not known in advance, since none has been subjected to pressure of this magnitude before.[109] Indeed, as already Lewontin complained, most nodal lines are inherently difficult to forecast, because of the diminutive, unremarkable additions leading up to them: another grain, another grain …[110] Lenin is reputed to have said that a revolution 'won't happen in our lifetime' weeks before the Tsar fell in February 1917; no one could predict that an Israeli truck killing four Palestinians in Gaza – just another grain – would spark the First Intifada or that the self-immolation of a street vendor would touch off the Arab Spring.[111] In the age of climate avalanches, a general maxim would be to 'expect the unexpected'.[112] But hunches, or even well-founded appraisals, can be formed about where tipping points are. Do they sit close

to 1°C or closer to 6°C? Grappling with this problem is imperative for assessing not only the prospects of removal: tipping points constitute the treacherous terrain on which every type of climate politics – adaptation, geoengineering and, of course, mitigation – has to move. This is the world we now live in.

Searching for lines in the sand

If the main tipping points are several degrees of warming away, a bit of overshoot might not hurt all that much. There could be time to stop emitting and start removing before truly catastrophic avalanches kick in. But if the points are near at hand – or even behind us – the challenges for any scheme of overshoot-and-return would be immense, as the crossing of limits might take us beyond the points of *no* return. So, which one is it? The unmistakable trend so far has been to move the nodal lines closer and closer to the present, gradualism being in graceless retreat, as visible in the brief stocktakings of the IPCC. In 2001, the Panel placed the phenomenon at a comfortable distance, on the other side of 5°C: fewer than two decades later, it was forced to acknowledge that several tipping points might be located between 1 and 2°C.[113] During the long afterlife of gradualism, one revision after another adjusted the expectations downwards. Experts voiced discomfort with prevailing calendars and a suspicion that elements would be tipped earlier than thought.[114]

Such was, indeed, the general sentiment on the research frontier, when the impacts of global warming struck with unseen force and speed and violence: ‘I am surprised by how far it is above the previous record,’ commented one climatologist after the season of destructive weather in 2021. ‘We seem to be not just above normal but in domains we didn’t expect’ – words typical for the moment, followed by a rueful afterthought: ‘We need to better model nonlinear events.’[115] ‘We could be in uncharted territory,’ another warned after temperature records were broken in droves in 2023. The models had no explanation for the 0.2°C surge in warming during that single year, which might ‘mean that statistical inferences based on past events are less reliable than we thought’. Such anomalies required urgent answers.[116] Already in 2015, one study tried to find them in the

literature and catalogued thirty-seven candidates for non-linear events, ranging from dieback of the Amazon rainforest to disappearance of the Himalayan snow: out of the thirty-seven, no fewer than eighteen would be activated below 2°C.[117] The authors concluded that the earth may 'experience sharp regional transitions at moderate warming, although the prediction of any particular event has a very high uncertainty': in brief, expect the unexpected.[118] In 2022, a team of researchers around Lenton presented a revised table for sixteen main points: eight would be crossed between 1.5°C and 2°C, two of which might have *already* been crossed, leading them to up the ante even further. The earth had been expelled from 'a safe climate state' when average warming exceeded 1°C, in the mid-2010s or thereabouts.[119]

A question here imposes itself: is there *one* tipping point for the climate system as a whole? Is it possible to identify a line cutting through the planetary totality as sharply as a border fence? Lenton has suggested that there is indeed one, and that it sits more than two centuries behind us: namely, 'the invention of the steam engine', which tipped the earth into uncontrolled heating.[120] But the conceptual drift between the sciences might here reach a blind alley.[121] The steam engine cannot have constituted a nodal line for humanity as 100°C does for water or a particular spike in insolation for an ice age: the reverberations were not physically determined at its inception; not all that has happened in the sphere of energy use was genetically present in Watt's workshop. While steam power can be said to have marked 'a fork in the road', a degree of openness and indeterminacy must be reserved for human history, allowing for other turns that *could* have been taken at later junctions, even if, in the event, they were not.[122] If the search for one all-encompassing tipping point is instead limited to the realm of climate *sensu stricto*, a related problem emerges. Not even this entity is a machine. It may be physically determined, but its components are not coupled and synchronised as those of an engine or computer.[123] The biosphere will not collapse in a single avalanche, like the incomparably simpler structure of a sandpile. Rather it consists of subsystems articulated with one other, each with its own temporality, whose relative autonomy remains to be assessed, somewhat like a Matryoshka doll or a tangle of nested loops. But it might still be the case that tipping points *cluster* around

a certain degree of warming: 1.5°C, or 2°C, or higher or lower. What are the best estimates for the elements of most pressing concern?

Refreezing an ice sheet

Few impacts cast such a long shadow over the future as sea level rise. It is the slumbering, slowly – so far – awakening giant of climate change, threatening to trample underfoot lands ever further from present shorelines. The rise could unfold over centuries or millennia, beyond the investment horizon of even the boldest removal entrepreneur.

Warm water takes up more volume than cold. If you heat water, it expands. Do so on a planetary scale and you have one of the drivers of sea level rise.[124] In this rapidly warming world, the oceans absorb enormous amounts of heat – at the time of this writing, the energy equivalent of seven atomic bombs fired into them every second.[125] But it takes time to penetrate deep waters. The exchange of heat between the air and the sea below the surface churns sluggishly, so that the warming of the latter lags decades or centuries behind. As for the deepest abysses, the lag is longer still: it might take thousands of years for them, and thereby the oceans as a whole, to attain full balance with the warm air.[126] As the atomic bombs shed their loads – a gradual process if ever there was one, but this is not for the better – the deeper waters expand in tandem. It follows that thermal expansion of the oceans will continue even after full disarmament, or zero emissions. Indeed, it will continue *even after removal has returned CO_2 concentration to pre-industrial peace*. This driver of sea level rise is likely to proceed apace for nearly a century after such a return has been completed, only then going into slow reverse. After more than one millennium, the oceans might, perhaps, have shrunk to their original size.[127] It further follows that 'sea level rise from thermal expansion is not reversible even under strong decreases in atmospheric CO_2 on timescales relevant to human civilisation'.[128] You can throw prodigious amounts of removal at the system and roll back temperatures all you want, small island states and coastal plains and deltas might still be consumed by rising waters. Overshoot,

meanwhile, means shooting more atomic bombs into the oceans for drawn-out shedding.

But this is only the beginning: thermal expansion is just one driver of sea level rise, leisurely and linear, with no tipping points.[129] It is otherwise with ice sheets. When they tip from land into sea and the ice dissolves in water, sea level rises. Now glaciology has its fair share of gradualist hang-ups and hangovers. 'Glacial pace' is an idiom for idiotic slowness of change, with some support in the discipline. 'According to glaciology textbooks, glaciers respond to climate change on timescales that vary from a decade or more for nonpolar glaciers' – in the Alps, Andes, Atlas and Himalayas – 'to millennia for polar ice sheets' on Greenland and Antarctica. 'These numbers have lured the scientific community into thinking that while small glaciers undergo rapid changes, the big ice sheets adjust at a leisurely pace,' two dissenters noted in 2007. They then added: 'Lately, the ice sheets have been teaching us differently.'[130] Or, in the words of another critical glaciologist: 'Ice sheets have taken tens of thousands of years to form and we have grown accustomed to the conservative view that they may change with eternal slowness' – ice sheets *non faciunt saltus*.[131] The classic method for measuring their 'mass balance' is to count accumulation against ablation, the plus of snowfall in winter against the minus of melting in summertime. If the minus wins, the unit retreats. The future is a function of how long it takes for the retreat to run its course – very long, on the scale of millennia, for the polar sheets. But such a crude calculator is not up to the task of grasping their behaviour in a rapidly warming world, as glaciologists began to realise during the first decade of this century, after discovering a suite of non-linear processes sorted under the rubric of 'glacier dynamics'. In reality, the sheets might behave rather like children climbing up one hell of a pool slide and riding it down.

This was and still is an ongoing clash between the poverty of models and the rich evidence from the past and present. The former led, as we have seen, the IPCC to miss the extent of sea level rise already observed. Unrealistic gradualism was particularly pronounced in the fourth assessment report from 2007 – the one for which the Panel received the Nobel Peace Prize – in which the forecast for sea level rise until 2100 was *lowered* to fifty-eight centimetres as the worst-case scenario.[132] (At that point, sea levels had risen by about twenty centimetres since the days of the steam engine.)[133] The Panel here explicitly discounted glacier dynamics,

even though it knew of their existence.[134] Discontent broke out in the ranks. The director of the British Antarctic Survey called the Panel 'restrained to the point of being seriously misleading'.[135] Hansen demanded the convocation of an alternative panel.[136] Researchers seeing the ice sheets sliding away towards the sea objected to the overreliance on models incapable of representing such moves.[137] By the beginning of the third decade, the IPCC had partly complied and revised the projection upwards: 1.1 metre was now said to be the worst-case scenario with some degree of likelihood.[138] But the crisis remained unresolved. In 2020, a team of unhappy glaciologists noted that 'model projections generally do not capture the abrupt and highly non-linear dynamics that are being observed today', and in the sixth assessment report from the following year, the unravelling of the gradualist paradigm for sea level rise was plain to see.[139] While the Panel retained one metre as the upper bound for modellable rise until 2100, it acknowledged that glacier dynamics – still the victim of 'missing or crude representation in model simulations' – might push it to 2.3 metres and further to 5 by 2150. Nothing suggested that this was the end of the revisionist trend.[140]

It was of more than academic interest. Unlike in similar revisions in evolutionary biology, the stakes were vertiginously high: gradualism or dialectics spelled the difference between annoying and biblical amounts of sea level rise. Will people be able to stick it out or have to move *en masse*? The continued reliance on models – computer code, that is – incapable of capturing observed trends and credibly predicting their development 'lead to a false sense of security', like climate gradualism in general.[141] Rarely has a scientific crisis had implications stretching as far into the future. 'Planning affecting tens to hundreds of millions of people is founded on the work of just a few tens of scientists.'[142]

Unlike the polar ice sheets, mountain glaciers have served as water tanks on the roofs for populations counting in the billions, above all in Asia. In the process of being emptied, they might generate outburst floods – transitional symptoms, on the way from too much to too little water – but their contribution to the sea will be but a trickle. They have the potential to raise the level by some thirty centimetres.[143] When will they be lost? According to Lenton and his colleagues, their tipping point sits in the vicinity of 2°C; with more warming, none will survive, although it might

take two centuries for them to be buried in the seas.[144] Half of the glaciers would not even outlive 1.5°C (but most in the Himalayas would).[145]

Greenland is a different story. It holds enough ice to raise sea levels by seven metres. In the early years of the millennium, scientists noticed that glaciers bordering the coastlines were beginning to act weirdly – in particular Jakobshavn Isbrae to the west, known for being the source of the iceberg that sank *Titanic*.[146] This mega-glacier was spewing icebergs. Until then, its outlets – fjords densely packed with ice – had been sealed by shelves, floating but attached to the mass of ice inland, holding it back, keeping it from flowing into the sea. The ice shelves functioned like corks in a bottle. As warm water lapped and warm air brushed against them, however, the shelves thinned and approached self-organised criticality and then fractured. The bottles were uncorked: the outlets of Jakobshavn Isbrae could run unimpeded and calve armadas of icebergs. Similar fractures, overturning the balance of forces between pressure from the interior and resistance at the margins, proliferated around Greenland during the first two decades of the millennium.[147]

The effects could be dramatic and immediate. When one glacier in Eastern Greenland became uncorked, it accelerated towards the sea and destabilised the 1,200-metre-high rock face that it supported. One day in September 2023, the whole rock collapsed in one moment, sending 25 million cubic metres of mountain and glacier sliding into a nearby fjord. This ‘rock-ice avalanche’ flowed more than two kilometres into the water, causing a ‘mega-tsunami’ that initially measured 200 metres in height.[148] Massive waves crashed back and forth across the narrow fjord for nine consecutive days, sending seismic waves across the planet in a pattern that was ‘so completely unprecedented’ that scientists sitting by their earthquake monitors failed at first to understand what was going on. ‘Never before has such a long-lasting, globally travelling seismic wave, containing only a single frequency of oscillation, been recorded’. Uncorked glacier triggers an avalanche that precipitates a tsunami that sets off earthquake sensors all the way to Antarctica and causes ‘the whole Earth to vibrate’.[149] Sometimes nature makes large leaps indeed.

Masses of ice that were uncorked soon became unstable in other ways as well. More cracks and crevices started forming on their surface.[150] These then joined forces with a second type of dynamic: when ice melted in the

summer, lakes formed on top of the glaciers. They grew and attained self-organised criticality and then, as soon as they came into contact with a crevice, drained away in hidden waterfalls and swirled down to the bedrock. There the meltwater lubricated the glaciers. It started lifting them over the sediments. It had the same effect on friction as water in a pool slide.[151] 'We used to think that it would take 10,000 years for melting at the surface to penetrate down to the bottom of the ice sheet,' recalled Alley. 'But if you make a lake on the surface and a crack opens and the water goes down the crack, it doesn't take 10,000 years, it takes ten seconds': and then the glaciers can glide towards the sea.[152] Here was another discovery of how the twenty-first century would work on Greenland.

A gear shift in the discharge of ice occurred around the turn of the millennium, controlled not by mass balance – plus versus minus in a straight line – but by dynamics, such as uncorking and lubrication.[153] These are likely to remain the dominant forces for the rest of the century.[154] But to the same extent, they are difficult to capture before the events. In all their variegation, the sliding mechanisms tend to catch scientists by surprise: one glacier long considered cloistered in stability was attacked by intruding warm sea waters in the summer of 2018 and responded by thinning, retreating, quadrupling its outflow speed – an acceleration never before seen – like a community so traumatised by a raiding expedition that it simply dissolves.[155] Then there are also positive feedback mechanisms to take into account. When a glacier melts, it loses elevation – Greenland departs from an altitude of 3,000 metres above the sea – and enters warmer air below, like a hiker descending from the peak; it then melts faster, and so on. White surfaces have a high albedo: they reflect sunlight back into space. Fresh snowpacks on the glaciers glisten in the sun. But when the melting scrubs away the top layers, older and darker strata are laid bare, gravelly ice with a low albedo, absorbing rather than repelling heat so that more ice melts, and so on.[156]

Combined with other dynamics, such self-reinforcing loops open for the possibility of a nodal line for Greenland, beyond which the entire ice sheet would slide into the worldwide pool with nothing to stop it. Where might the line be? An earlier estimate was 3.1°C; but after two decades of dialectics in real time, it rather converged on 1.6°C.[157] This also conformed with evidence from the last glacial cycles.[158] A more optimistic estimate,

based on conservative modelling, came up with a low line of 1.7°C and a high of 2.3°C, beyond which the sheet would be doomed to disappearance: not much further from the present.[159] 1.6°C, incidentally, marks the lowest level of overshoot. At the time of this writing, we are a hair's breadth away from it, and researchers have just reported 'early warning signals' indicating that the central and western bulk of the sheet is 'close to a critical transition'.[160]

If Greenland is tipped tomorrow, this does not mean that it all lies in the pool ten seconds later. It might take one whole millennium for the seven metres to be realised – or much less, depending on how intense the forcing is.[161] A long period of high temperature rise will, it goes without saying, execute the death sentence much faster than a short of low. Conservative-optimist modelling even suggests that if merely a toe passes the threshold and is then quickly drawn back, all ice would not necessarily be lost.[162] On the other hand, there are signs of strong hysteresis in this system. If thrown into the sea, Greenland will not climb back up of its own accord. Nor would it be enough to return the CO_2 concentration to pre-industrial levels. This ice sheet would be a legacy from the last ice age amenable for restoration *only if so much CO_2 is removed from the atmosphere as to bring about a new ice age* – once the loss has taken on a dynamic of its own, nothing less could refreeze it.[163] The nodal line where this happens might be 0.4 of the 7 metres of sea level the Greenland sheet holds; when the equivalent of forty centimetres have been discharged, that is, the sheet will have passed a threshold beyond which only glaciation can make it regrow.[164] This would entail an ice age covering much of America and Europe too. Feasibility issues aside, this would presumably be one step too far for even the most ambitious time machine.

Antarctica presents a picture both different and similar. It makes Greenland look like a dwarf. If all of it were to plunge into the surrounding seas, they would rise by fifty-seven metres. Five would come from the western part of the sheet, the bulge topped by the peninsula; fifty-two from the deep-frozen east. No other continent has been placed so far outside of history. None has rivalled it as the picture of eternal stillness, where even gradual change would be freakish. Antarctica was long perceived as insulated from global warming, too deeply embedded in the cold to be touched: all the greater the shocks of the millennium, beginning in the

summer of 2002, at the eastern tip of the peninsula that stretches towards Cape Horn like a Michelangelo finger. An ice shelf known as Larsen B had been there throughout the Holocene. It was named after a Norwegian captain who passed by on a steamboat in 1893. But during this warm southern summer, the shelf became dotted with ponds of meltwater, and the meltwater functioned as wedges, and the ongoing contradiction between the warming sea and air and the hitherto existing order intensified, until the shelf cracked and splintered and turned into a slush of ice floes that departed the peninsula for good. Most of the collapse took place over three days. The glacier hitherto buttressed by Larsen B then sped up its outflow by a factor of three.[165]

Stunned scientists began to understand that the West Antarctic ice sheet is as vulnerable to uncorking as Greenland, if not more so, since much of it sits below sea level and is precariously plugged. A mélange of buoyant shelves, cliffs, tongues restrain the tributaries that press on from the interior: each forms a microcosm of dialectics, prone to self-organised criticality.[166] Each little system can undergo a local avalanche. The glaciers behind will then leap ahead into the sea, in jumps that can make them lose up to 600 metres per day.[167] Warm waters can slip furtively into cavities and move over bedslopes and carry off glacier mass into the ocean.[168] The southern summer of 2023 produced another season of shock and awe, when sea ice in all its forms around Antarctica reached a record low; compared to the average from the past forty years, an area larger than Western Europe had gone missing.[169] ‘It’s not often in my career when scientists have really been gobsmacked by what they’re seeing, but people have really been alarmed,’ commented one expert. ‘We knew that substantial change was coming down the pipeline, but we have seen processes that we thought might play out in the middle of the century playing out much sooner.’[170] This reaction by now formed a familiar pattern, in the face of natural history accelerating like a sprinting cheetah.

When the buttresses are gone, not only do the glaciers have an open exit, but the warming water can lick them at their mouths, propagating heat straight into them; and when white ice gives way to dark blue ocean, the albedo is reduced, more heat soaked up by the surface, and so on. The elevation feedback is present in Antarctica too. Lakes exploding and lubricating the glaciers have been observed, including lakes *inside* the

glaciers, spreading through invisible channels to their bottoms.[171] Dynamics of this sort might constitute a tipping point for, to begin with, the western part of the sheet: where roughly? An early estimate that counted only the balance between snowfall and melting said 8°C.[172] That would have been reassuring. Carbon dioxide removal would have had plenty of time to work its wonders. But more comprehensive assessments including glacier dynamics came up first with 2°C, then with 1.5°C, and then with the conclusion that *the nodal line for western Antarctica has already been crossed*.[173] Case in point, the popularly named 'doomsday' Thwaites glacier appears to be in terminal decline.[174] Its fall into the sea would 'destabilise the rest of the West Antarctic ice sheet like toppling dominoes', and such processes may have been unstoppable since circa the mid-2010s, leading one trio of researchers to conclude that 'the opportunity to preserve the sheet in its present-day state has probably passed'.[175] This trio ended their article with the hope that life with the now unavoidable sea level rise will be abetted by 'luck'.[176] That was an unusual way to round off a peer-reviewed paper in climate science. They might as well have written 'God help us.'

What of eastern Antarctica? Heart of brightness and motionless eternity, it has likewise been drawn into history in recent decades, when dynamic processes of the same kind have been observed.[177] Not even these vast expanses are isolated from the warming. Shelves can splinter and warm waters slither deep inland here too.[178] In March 2022, the largest heatwave ever recorded struck eastern Antarctica, although 'heat' is a relative concept: temperatures stood 39°C higher than normal, at –10°C.[179] The ability of an average global temperature rise of around 1.2°C to produce a regional spike of 39°C did not bode well for the near future. But the best estimate, as of this writing, still places the tipping point for the east at 8 to 10°C (down from a non-dynamic 16°C).[180] Here would then be some real room for manoeuvre. If the five metres from the west can no longer be averted, (most of) the fifty-two from the east can. Given the way the winds of climate and science blow, however, one should perhaps not be lulled into a sense of security in this region either.

A threshold of 3°C has been proposed for Antarctica as a whole, beyond which ice loss would make a quantum leap.[181] Such warming could easily be generated by business-as-usual during the present century: but it could also be thwarted. Much as for Greenland, the pace of melting could still be

regulated after a line has been crossed – large emissions expediting it and vice versa – but once underway, it would progress regardless of whether emissions continue or stop or turn negative. There would be hysteresis. Refreezing a lost Antarctic ice sheet would require that temperatures go 3 or 4°C below the pre-industrial baseline – removal so massive, again, as to reverse back into deep glaciation.[182] If overshoot were to halt at 2°C, in other words, we might need to remove so much CO_2 as to slash average temperatures by 6°C to get the West Antarctic ice sheet back in place. It is not immediately clear that this would be feasible under any constellation of negative emissions technologies.

Overshoot-and-return is, in general, not a very useful approach to sea level rise *precisely because of its non-linear, dialectical, historical nature*. Ice sheets and oceans do not form a machine. Every tenth of a degree brings the nodal lines closer on all scales, from a recently formed meltwater pond on some remote ice shelf to a whole continental cover; every additional warming condoned in the spirit of 'temporary' overshoot might cause irreparable damage. One study has suggested that every decade of overshoot above 1.5°C would yield four extra centimetres of sea level rise, but this should be read as a rough approximation.[183] Four centimetres are, incidentally, the rate by which sea levels rose during the waning of the last ice age *per year*. Since the forcing is of another magnitude this time, the rate observed so far – the three millimetres underestimated by the IPCC – is poised for a speed-up.[184] Any overshoot tied to the promise of removal would risk letting it loose. Aiming for a new ice age by way of compensation would be to bet on technologies of practically boundless capacity, and to fancy a global cooling potentially as disruptive as the prior warming. The conclusion must be that committed sea level rise *cannot be reversed by means of carbon dioxide removal*.[185]

Running amok with the oceans

Gradualism may have permeated the natural sciences, but it does not work well on screen. In *The Day after Tomorrow*, a clichéd apocalyptic film from 2004, Greenland gushes into the sea, the oceans erupt in hysterical outbreaks, ice hurricanes sweep the Atlantic seaboards, temperatures drop

by 10°C per second and the Statue of Liberty is encased in frost. Bearing no relation to science, the film nevertheless solidified the status of a collapsing Gulf Stream as the poster-child tipping point. Perhaps it spoke to an archetypal fear of cooling on northern latitudes (‘winter is coming’, as in *Game of Thrones*). But the fate of ocean currents in a warming world is indeed a real concern.

If insolation is the beating heart of the earth system, then ocean currents are the aorta through which energy is pumped around the globe. They operate through the interplay of two variables: temperature and salinity. Cold water is denser than warm (just as with air: the lowest bench in a sauna is the coolest). Saltwater is denser than fresh. If you pour salt into a glass, it drizzles to the bottom. Waters with low temperatures and high salinity thus tend to fall towards the depths of the oceans, whereas warm and fresh waters rise towards the surface, and it is the dance of these opposites that keeps the currents in motion, in splendid dialectical choreography.[186] Things are the way they are on Earth, to no small degree because opposing forces distribute the heat streaming in from the sun. Cold and salty waters in the northern Atlantic dive towards the bottom; warmer waters from the equator are pulled towards the north, where they can fill the vacated upper layers, until they too cool down and start their descent; and round and round the currents go, conveying heat from the latitudes of the most intense insolation. The so-called Gulf Stream sends warm waters from the Caribbean towards Ireland, Britain and Scandinavia; but it is only one moment in the greater Atlantic Meridional Overturning Circulation, commonly abbreviated AMOC. Just as important is the southward flow of cold waters, back towards the tropics and further to Antarctica, where it connects with other planet-wide currents in a totality as beautiful and intricate as it is beneficial: AMOC gives Europe its mild climate and ventilates the tropics. Without its delicate balance, both Europe and the tropics would be far less hospitable – the former too cold, the latter too hot.[187]

But dialectics teaches us that equilibrium cannot be taken for granted. As long as the parameters remain within limits, stability reigns; but sooner or later, those parameters become ‘subject to change’ and ‘cross the threshold beyond which the original system can no longer persist as it was’.[188] Temperature and salinity are not impervious to change. AMOC is especially sensitive to the latter parameter. If the atmosphere warms up, it holds more

water, generating more violent and abundant rainfall (when it rains, that is): the hydrological cycle intensifies. Since rain consists of freshwater, adding more of it to the oceans dilutes their salinity. If these oceans also receive freshwater from some other source, say a mass of ice melting somewhere in the vicinity, the effect is enhanced: salinity reduced further, until the waters sink no more.[189] This is the weak point of AMOC. If we think of the circulation of currents as a waltz, it is the salty, northern partner that leads, but it is prone to slowing down and collapsing in a chair. When it does, the Atlantic north will no longer be embraced by warm waters from the south; if never by 10°C per second, temperatures may abruptly plunge. Swings in the moods and modalities of AMOC have been identified in the many episodes of cooling during the last glacial cycle, such as the Dansgaard–Oeschger events and the great glacial lake outburst flood 8,200 years ago.[190] When a bucket of meltwater was poured into the North Atlantic, AMOC would slow or stop.[191] Once again, this past record may hold keys to the near future.

The picture first conjured up is that of a frigid north: the Statue of Liberty in a dress of frost. And, indeed, some modelling predicts that an AMOC collapse would cut temperatures by 10°C in parts of the Arctic.[192] One study calculated the effect on Great Britain and predicted a drop of 3.4°C – larger than the prior rise due to global warming.[193] Another showed that cooling would be particularly extreme in winter, with temperatures for February plummeting by as much as 15°C in London and 35°C in Bergen on the Norwegian coast.[194] One might be tempted to cheer this on as the earth rectifying the ills of humanity, but that would be to miss the implications. How would life in London or Bergen go on under such a freeze? If northern Europe were to cool this dramatically, it would also be deprived of precipitation – the hydrological cycle would slacken; there would be less rain. An epic drought could decimate the areas suitable for farming in Britain, a blow to the country ‘an order of magnitude larger than the impacts of climate change without an AMOC collapse’.[195] Climate change in Europe would bifurcate: the south would continue to warm and run into a cooling north across a frontline stretching roughly from Brittany in France over northern Germany to the Baltic countries. This would be ground zero for large swings in temperature and precipitation and exceedingly extreme weather events.[196]

North of the *limes*, the albedo feedback could keep the snow and ice marching onwards and temperatures fall by 'more than 3°C *per decade*'.[197] This compares to a rate of warming of 0.2°C per decade so far. 'No realistic adaptation measures can deal with such rapid temperature changes under an AMOC collapse': the end of northern Europe as we know it.[198] One might welcome this quasi-ice age as a salvation for Greenland. It would cool down. The dynamics could be put on hold. (Although some research suggests that the ensuing reduction in precipitation – snowfall – would 'lead to the opposite effect and destabilise the sheet even more'.[199] The climate system is nothing if not complex.) Then there are also forecasts suggesting that the cooling would be rather less severe if the underlying warming is strong and persistent enough. Were AMOC to collapse in the middle of this century, northern Europe might experience a relapse to temperatures from before the steam engine or a relief from their rise; either could be short-lived if business-as-usual remains in operation.[200]

Equal or greater misery might lie in store for the south. The metaphor for AMOC most common in the literature is both mechanical and Eurocentric – a 'conveyor belt' delivering 'groceries for the people of Europe' – but in a warming world, it might perform its greatest services for the tropics.[201] Without it, more heat would be trapped along the equator *and the warming in the south would be amplified*.[202] Cooler and drier conditions to the north would dislocate the precipitation patterns on which so many southern countries depend. The monsoons that shower Mesoamerica and West Africa could be pushed southwards out of their tracks, which would dry up lands from the Amazon to the Sahel and cut the local supply of all sorts of 'groceries'.[203] These are the monsoons that have enabled agriculture in countries like Mexico since the onset of the Holocene.[204] But the effects on monsoons could stretch much farther afield, to the Indian subcontinent and beyond: because AMOC connects with so many regions and touches on so many ecosystems, a slowdown or shutdown would reverberate across the globe.[205] It has done so repeatedly in history. These are the teleconnections of the climate system – *tele* as in television, teleportation, telepathy – that tie together the most distant places in a mesh of arteries. After a collapse, Antarctica would see more heat coming its way. But AMOC transports more than just heat; it also shuffles around water as such.[206] Oceans are in fact not flat but tend to be slightly inclined because of prevailing currents.

Without AMOC, massive volumes would be stranded in places they would normally leave. In this regard, the north would have it worse: post-AMOC sea levels would fall back in the south but climb even further along the western coasts of Europe and the eastern of the US, perhaps by as much as one metre.[207]

How, then, is the AMOC faring? It has undergone a well-documented weakening since 2004 – ironically, the year when *Day after Tomorrow* appeared.[208] The sources of the trend are no mystery: increased rainfall over the north Atlantic, hitting the oceans directly or via river run-off, plus accelerated discharge from Greenland.[209] In the early 2020s, AMOC was weaker than at any point in the past 1,000 years.[210] The result, as of this writing, is immediately visible on any map that tracks the global rise in temperatures over the past decades. Invariably, these maps bloom in various shades of yellow, orange and the most alarming deep red. But an exception strikes the eye: a blue spot just to the south of Greenland and Iceland, indicating that here and here alone, the trend is one of cooling. The phenomenon is referred to as the north Atlantic 'warming hole', or more popularly 'the cold blob'.[211] It is the fingerprint of a weakening AMOC. Symptoms of the ongoing dishevelment, the cold blob may have exacerbated recent *heatwaves* in Europe: it appears to have an uncanny tendency to plant high-pressure weather systems over the central continent for weeks on end.[212] On the other side of the Atlantic, weakening AMOC has caused jumps in the sea level, by thirteen centimetres along the New York coastline in the winter of 2009–10 alone.[213] Already now, with the balance of opposing forces upset, things are not quite the way they used to be.

But this is still more like the day before tomorrow, because AMOC may not weaken linearly. In fact, the flips it has experienced in the past form the paradigmatic case of abrupt climate change. This system exhibits punctuated equilibrium, or a tendency to self-organised criticality:

> Increased freshwater input into the Nordic Seas will initially weaken the circulation only slowly. But when a certain threshold is reached, the circulation may jump abruptly to a new state in which there is little or no heat flux to the north. The system is highly nonlinear and *will not immediately switch back to the warm mode when the freshwater input weakens*.[214]

Here, then, is another tipping element of the first order. Where is its point? Much as the ice sheets, AMOC was long considered a headache for future generations; but over time, one warning light after another came on, and by now much of the dashboard is flashing a shrill red. In the IPCC's *Special Report on the Ocean and Cryosphere* from 2019, an AMOC collapse during this century was deemed 'very unlikely but physically plausible'.[215] By the time of the sixth assessment report from 2021, the Panel, ever weighing its words on a scale of cautious nuance, classified the event as merely 'unlikely'. Best estimates then said that the AMOC would tip at 4°C.[216] But the models yielding this result were marred by 'unrealistic stability', since they disregarded dynamical processes, not the least on Greenland itself.[217] The Panel recognised this and added that 'there is *medium confidence* that the decline in AMOC will not involve an abrupt collapse before 2100', a phrasing that did not exude much confidence at all.[218] Indeed, the Panel acknowledged that 'a collapse of AMOC can be induced, even by small-amplitude changes in freshwater forcing': one drop, one drop, one drop, until one more drop makes the northern partner stop dead in its tracks.[219]

This was not, predictably, the last attempt to wash away the stains of gradualism. Some models endeavouring to more realistically represent non-linear causation found nodal lines between 2.2°C and 2.5°C or between 1.4°C and 1.9°C.[220] More recently, two Danish specialists – also from that home institute for self-organised criticality – predicted 'with high confidence' that a total collapse of AMOC will happen 'as soon as mid-century' under current trends of warming, and with 95 per cent confidence sometime between 2025 and 2095. They interpreted the slowdown and influx of freshwater as 'clear indications of imminent collapse'.[221] These Danes were not alone in ringing the alarm bell; the unrelenting acceleration of the ice loss from Greenland was widely seen as pushing AMOC closer and closer to the nodal line.[222] In early 2024, it was revealed that such loss since the gear shift at the turn of the millennium was one fifth larger than previously thought.[223] (And the same news came in from the extreme south, where the faster melting of the Antarctic ice sheet threatened to run amok with another branch of ocean currents.)[224]

By October 2024, the risk of a collapse was real enough for forty-four prominent climate scientists to write an open letter to the Nordic Council of Ministers. It started by laying out the evidence from recent studies and the

likelihood that IPCC estimates would need to be revised. But even the Panel's current 'medium confidence' that the AMOC would persist, the authors reminded the Council, was 'not reassuring' given the 'catastrophic' consequences a shutdown would have. Agriculture might become unviable across large parts of north-western Europe. There could be no adaptation to such a twist of fate, and so – by now a shopworn summons – the ministers and their fellow policymakers were told to keep the world close to 1.5°C.[225] The letter thereby laid out the stakes in unambiguous terms: no minister of the north could henceforth claim to be uninformed of the white walkers lurking beyond the wall of Paris. This did not, however, signify the completion of a new scientific consensus. Questions were still raised over the AMOC schedule. One study published in early 2025 cast doubt on the evidence that the current had indeed weakened in past decades by using a different method of calculation.[226] Another appeared to show that at least a much-weakened AMOC could persist even under extreme warming.[227] The field of AMOC studies had not yet crossed its own nodal line. But precisely because the future of the circulation now looked so uncertain, the possibility of its ending could no longer be dismissed.

Might a collapsed system be enticed to revive? The 'bi-stability' of AMOC, its tendency to be either on or off, either prostrate or running, implies hysteresis after the freshwater influx has stopped.[228] But a restart somewhere down the line appears possible.[229] With sufficiently large removals, the great currents could be prodded into prelapsarian motion.[230] It could take ages, though, especially if the long meltdown of Greenland first has to be overturned. The IPCC thinks it could be done over a period of multiple centuries.[231] It is unclear if it has considered the imaginative solution put forth in *Fifty Degrees Below*, one volume from Kim Stanley Robinson's growing shelf of cli-fi novels. Here an American team of hero scientists struggle with an abrupt collapse of AMOC and a big freeze on the east coast. They come up with a plan to jumpstart the circulation by tipping 500 million tonnes of salt – twice the world's annual production – into the Atlantic. The world's fleet of oil tankers is repurposed for the project ('The real problem here', one technocrat muses while drafting the plan, 'would be maintaining oil supplies at an adequate level with so much shipping taken out of transport all at once.')[232] The necessary vessels eventually line up and congregate south of Iceland to synchronise delivery of their payload.

‘There came a moment when the tankers dotted the ocean’s surface for as far as they could see in all directions, spread out like iron filings in a magnetic field, all pointing north.’[233] The novel ends without narrating the outcome of the ocean engineering project; so far, it remains a fictional idea. But if we can imagine shooting snow onto the sheets or pumping sulphur into the stratosphere, why not also pouring salt into the Atlantic? Presumably, it is just a matter of time before a Californian startup catches up with the fiction and starts selling advance carbon credits to finance its realisation.

Not even the dead will be safe

Floating ice can dissolve in the sea without raising it, just like an ice cube in a full glass of water disappears without a spill. The melting of ice in the Arctic Ocean does not affect sea levels directly. Since it is ruled by the most basic Hegelian nodal line – solid becomes liquid over 0°C – the loss would likely be reversible, the sea ice reforming as soon as removals return temperatures to the freezing point, as when water is put into a fridge; no glaciation would be needed here.[234] But unfortunately, the path to such a happy ending might be complicated by coils and twists in the systems. The albedo feedback has caused the Arctic to warm four times faster than the global average since reliable satellite observations began in 1979 (not twice as fast, as previously thought). The speed eludes computer models.[235] It has become an emblem of breakdown: the white bonnet on the earth cut by the sun every summer, revealing oceans as dark blue as a bruise. With more heat stored, it is harder for ice to form in the autumn; the remaining sheet is thin and fragile, easily hurt by heatwaves or storms.[236] The speed and staggered rhythm of this process has likewise flummoxed the Panel and other forecasters, contributing to the crisis of climate gradualism and raising the spectre of a regional nodal line: a summer with no ice at all in the Arctic Ocean.[237]

As of this writing, the best forecast puts the first ice-free summer somewhere between 2030 and 2040 and the tipping point for when this becomes the new normal between 1.5°C and 2°C – in the imminent overshoot range, that is.[238] An open blue ocean the year around would

require considerably more warming. One model from the most gradualist period of the IPCC expected it to be 13°C, but ongoing feedbacks point to an earlier-than-thought ice-free winter too.[239] Indeed, some kind of transition in the Arctic already appears in progress, the thinning and withdrawal having fundamentally altered the region: 'this "ecosystem of ice" no longer exists' as we knew it.[240] And while the ice can potentially be restored at a later date, the loss might set off other, less reversible avalanches in the interim. An ice-free Arctic would wrap Greenland in warm waters.[241] Because the white ice has functioned as a 'global refrigerator', cooling the planet as a whole by reflecting sunlight back into space, its disappearance would skew the energy balance further: in one estimate, 1.5°C of average warming would produce an additional 0.2°C from a darkening Arctic alone.[242] But some of the riskier knock-on effects would, again, play out in the immediate vicinity, namely in the permafrost.

Lining the Arctic Ocean, covering vast swathes of Canada, Russia and Scandinavia, the permafrost holds the remains from animals and plants that have died on land too cold for microbes to do their work of decomposition: a frozen mass grave of organic matter. Since the carbon in those bodies and bones and roots has not been released into the air, it forms the largest terrestrial pool of the element. The amount of carbon holed up here is four times larger than that emitted by humans since the nineteenth century. Slabs of hard, thick, brownish soil packed with the matter extend metres, sometimes a kilometre and a half into the ground.[243] When the region warms, the nodal line for thawing can be crossed and microbes spring back into action like a myriad of invisible tomb raiders sending carbon into the atmosphere, in the form of either CO_2 or CH_4. The disinterred carbon might have been buried tens of thousands of years ago, during the Pleistocene epoch of woolly mammoths, sealed away from the active cycle but now thrown into it: a positive feedback mechanism of the warming itself.[244] But a climate science still bound by the conception of causation as a line rather than a spiral has had difficulty incorporating this loop. In fact, standard estimates of the carbon budgets for 1.5°C or 2°C have simply omitted emissions from thawing permafrost.[245] The latter budget might have to be reduced by more than one third if they are included.[246] Put differently, it takes smaller anthropogenic emissions to reach any given temperature if the secondary emissions they provoke from this natural storehouse are

accounted for – and conversely, *it would take greater amounts of removal to return to any given level*.[247]

The warmer the Arctic, the smaller the ice cover on its ocean, the more heat in the rims of the permafrost, and so on; and this feedback is not held in abeyance.[248] Already by the early 2020s, emissions from thawing permafrost equalled those from Japan, the third largest capitalist economy.[249] Climate science strove to catch up with this fast-moving object, in a manner we can now find almost mechanically monotonous. Not only had the thawing been left out of most models and budgets; it had itself been mostly conceived as a gradual process, proceeding vertically through the column of soil in sync with the warming. The heat would slowly leach into the ground, perhaps a centimetre or two per decade.[250] 'Current evidence suggests a gradual and prolonged release,' one could read in *Nature* in 2015.[251] But again, reality proved rather more dialectical, and the 'current evidence' did not survive the mid-2010s.

When the ice pores melt, water seeps through the ground and saturates it until a point where it can no longer stay together: suddenly it subsides. Lakes – or slumps, troughs, gullies and other irregular features of what is known as 'thermokarst' – open up. Landslides can flay hills and expose their contents to respiration. When the land cracks in such localised avalanches, the depths are turned inside out and far more organic matter swept up and served to the microbes than when temperatures percolate in a mechanistic fashion. If the fissures are waterlogged – anoxic – the carbon will be released as methane, the far more potent greenhouse gas, of course, and the water will tend to continue moving and draining, laterally expanding the zone of decomposition. Still for tens of thousands of years, strata of carbon can be mobilised in a matter of days to years.[252] By the early 2020s, scars of thermokarst pockmarked much of the domain, these erosional features of the process having increased sixtyfold in four decades. Craters belching out methane and 'drunken trees' around thaw lakes – trees drooping without firm ground under their feet – became tell-tale signs of the avalanches rolling through the ground.[253] They were set to gather force and extend their reach through the region. Rainfall and wildfires, ever more common in the warming Arctic, will spur them on.[254]

The first, preliminary, conservative estimates suggested that emissions from abrupt will surpass those from gradual thawing during the present

century.[255] Still, the former are ‘entirely missing’ from climate models.[256] Closing eyes to the field observations, those models have room only for ‘a gradual top-down process where warming air thaws the ground uniformly across the landscape’.[257] Thermokarst, the proverbial elephant in that room, risks upsetting the balance of the carbon cycle severely. It also has another degree of irreversibility. The cracking of the landscape cannot be easily undone, and once it has been set in motion, carbon might continue to bubble away in fits and starts for many decades after CO_2 concentrations start to dwindle.[258] A nodal line of this nature – the permafrost pushed into abrupt thawing – has, again, been drawn straight through the present. The best estimate in the early 2020s put it at 1.5°C.[259] But it might also have been crossed already.[260] Two scientists claimed that the permafrost entered a self-sustaining loop of thawing after warming exceeded *one half of a degree Celsius*, in the 1960s; all that can be done ever since is to dampen it.[261] This still allows for big differences between 1.5°C and unreformed business-as-usual during the rest of the century.[262] To the same extent, any overshoot would produce ‘legacy effects’ – scars in the landscapes that would not heal for centuries; a genie of carbon out of its bottle.[263]

By the early 2020s, this was one of the hottest frontiers of climate research. Indeed, as we write this, a study has just been published about another kind of avalanche in the far north: after a series of ‘atmospheric rivers’ of record heat and rainfall in the summer of 2022, thousands of lakes in western Greenland underwent a metamorphosis. Crystal clear and blue for millennia, they turned murky and brown. Organic matter from the surrounding land was flushed into them as into a sewer. ‘The magnitude of colour change in less than 1 year in these lakes was comparable to that which occurs in boreal lake ontogeny [the developmental history of lakes] over hundreds to thousands of years.’[264] Until this year zero, the lakes had been holding carbon derived from aquatic plants and algae inside their tranquil pools. Now microbes set to work on it, and on the fresh inputs from the rivers. No longer sinks but sources, the darkly stained lakes tripled their flux of carbon dioxide into the atmosphere; methane went the same way. Future extreme weather could now be expected to wash down matter and spread ‘brownification’ across the Arctic.[265]

For every acre lost and every new observation of rapidly respiring soil, scientists brought home the conclusion that it is too late to save much of the

permafrost and soon too late to save most of it. 1.5°C would then have to be considered an insufficiently ambitious temperature target. Instead, we should recognise that we have been in overshoot territory for decades – perhaps half a century – and aim to go back towards 0°C of warming. But this could obviously be done only through negative emissions technologies.[266] It can be argued that the permafrost factor supercharges all types of climate politics with urgency: there must be mitigation, adaptation, removal, geoengineering – all of it, as much as physically possible, this very morning. The irreversible changes gaining momentum would here add to the case not against removal but for its maximisation. The two scientists who identified a 'point-of-no-return' in the 1960s inferred that humanity would need to build at least 33,000 'big' removal plants and 'keep them running forever' to have any chance of avoiding 'self-sustained temperature rise in the centuries ahead', or otherwise engage in solar geoengineering. But the latter would have 'unintended and undesired side effects' of its own.[267] So would the former. We shall inspect both in what follows.

If a tree falls

Then there are the forests. The Amazon is their jewel. The world's largest rainforest, it has a renowned capacity to create itself: roots reach deep into the soil to pump water for photosynthesis. The water rises through trees and departs them as moisture transpired from leaves. Clouds form above the canopy and release fresh rain, on which trees can sip for further photosynthesis and so on. Incoming rain is recycled, each water molecule making up to six rounds through ground, stem, leaf, air, cloud and back down again, before exiting the Amazon to the western mountains or the eastern sea. Steaming up from the transpiring trees, these 'flying rivers' nourish an exuberance of vegetation and maintain the rainforest in a stable state: but only if the tree cover is left standing.[268] It is the trees that create and recreate themselves. If they were to fall in large enough numbers, the mechanisms for recycling moisture might go into reverse: a shortage of humidity would grip the forest, more trees die, still less vapour be breathed into the air and so on, in a spiral of dieback driving the Amazon into the alternative state of a dry scrubland or grassland – or, in a word, savanna.[269]

This would be an earth-shattering catastrophe. The Amazon rainforest has been standing for 65 million years.[270] If human actions were to kill it, a caesura would be opened in history: here is one of the tipping elements with an Adornian potential to match the major catastrophes of the twentieth century – the trenches, the camps, the atomic bomb – in a destructiveness so intense as to defy comprehension and inflict a damage on the world, on the meaning of civilisation and the notions of goodness and beauty, that could be irreparable. Would it be possible to write poetry after the Amazon?[271]

The immediate victims would, of course, be the indigenous and Afrodescendent and other people of the Amazon, some 40 million in all, who would live through the end of a world.[272] Along them would perish species without number. The most biodiverse ecosystem by far, this 0.5 per cent of the planet's surface is home to more than one tenth of all named plant and vertebrate species; but then only about one tenth of the species of the Amazon have been named, the rest yet to be ferreted out from the niches of lushness and into the ledgers of science.[273] The vegetation and soil hold carbon equivalent to one fourth of that emitted since the nineteenth century. Smaller by an order of magnitude than the stocks of the permafrost, it would be enough to add 85 ppm or some 0.5°C – another positive feedback mechanism of the warming – and the warming is already tampering with the rainforest.[274] If less rain falls on the Amazon, there is less initial moisture to recycle. This could in itself turn the virtuous cycle vicious.[275] And less rain is now a feature of life in the Amazon: between the 1980s and the 2020s, the dry season became one week longer for every decade in the south-east, the most rapidly changing sector.[276] Drought recurred with greater frequency. In the first two decades of the twenty-first century, the Amazon was gripped by three 'one-in-a-century' droughts – in 2005, in 2010, in 2015 – or, put differently, a drought so massive as to be expected once per normal century now happened every fifth year, each larger than its predecessor; and the cause of the trend was global warming.[277]

Drought by itself increases tree mortality. A dry forest is also more susceptible to fire. As they shower themselves in their vaporous breath, rainforests are virtually immune to fire, but if trees begin to dry out and fall and more sunlight reaches the forest floor and further dries out the litter, there is plenty of flammable material: an *iskra* can set it ablaze.[278] Between the 1980s and the 2020s, the fire season in the Amazon doubled in length,

by 39 days, more than in any other forested region.[279] During the drought of 2015, the burned area was seven times larger than all the burned area of the four decades prior, and afterwards, scientists could observe how patches of rainforest in the central interior had in fact transmogrified into savanna. Fires along floodplains destroyed trunks and root mats and left the hitherto clayey soil exposed to erosion; in its place emerged white sand. The trees were replaced by scattered bushes.[280] Even larger fires – or 'megafires' – would be one probable form of avalanche pushing the Amazon, or parts of it, into a degraded savanna state.[281] That state would ensure its own self-reproduction. Once fires have razed the recycling mechanisms, any remaining vegetation will be deprived of the water needed to grow quickly and suppress further fires: the denuded post-Amazon fixed in a basin of attraction.[282]

But global warming is not, of course, the sole skulking executioner of the Amazon; deforestation is its companion, and the original reason for the worry about disrupted recycling.[283] Trees cut down are so many sources of moisture closed. Rainwater runs off in their absence and the air heats up: a related loop of desiccation.[284] In the sandpile model, only one hand sprinkles grains. Only one bartender feeds Mr Creosote. But in the ecosystems of the real world, no stressor works in isolation; global warming is not the only tendency intensifying contradictions, nor is it always the most aggressive.[285] The Amazon has long been mutilated by logging in the pursuit of commodity frontiers.[286] Much of it has happened through the element of fire, most notoriously under the watch of Jair Bolsonaro.[287] The modern worry, in other words, is that deforestation and warming will strike in concert at the roots of this biome. On its own, either assailant would be less effective. Through mutual reinforcement, they might together be six times more powerful as agents of destruction than either would be alone.[288]

Early estimates said that the Amazon would start sliding towards savanna if 40 per cent of the forest were to be cleared. The same would happen if warming reached 4°C. Dieback was thereby placed towards the end of the twenty-first century, and this as late as in the mid-2010s; then followed the abrupt revisions.[289] Before the 2010s had come to an end, the leading experts had cut the nodal line for deforestation to somewhere between 20 and 25 per cent, the process strengthened by the synergistic warming.[290] By then, some 17 per cent of the pre-Columbian rainforest had been cleared.[291]

In 2023, the share was put at 20.[292] No one seemed to speak about the end of the century any longer – except, unsurprisingly, the IPCC.[293] The best estimate in early 2024 identified 1.5°C as the 'safe boundary' against savannisation.[294] The forest reverberated with early warning signals – or, in Lewontinian language, 'the recovery rate after perturbations decreases and eventually approaches zero'.[295] The ball hovers on the ridge. Up-to-the-minute literature sounded the tocsin: 'The tipping point is here, it is now'; the duo of destroyers 'may already have pushed the Amazon close to a critical threshold'; 'the Amazon is currently perched to transition rapidly from a largely forested to a nonforested landscape'; 'the forest's tipping point is coming closer – and it's coming quick.'[296] It was coming quickest in the south-east, the 'arch of deforestation' in Brazil, the zone warming and desiccating and burning the most. The west of the Amazon would likely survive for longer, as rainfall is more abundant where the airmasses rise towards the peaks of the Andes.[297]

But the Amazon is a totality, and what happens in the south-east influences even the most protected corners. A dried-out margin will send less moisture with the wind. The south-east may well be the Achilles heel of the system.[298] It appears to have switched from a sink to a source of carbon already during the 2010s.[299] Here, in other words, the rainforest was dying more than growing, respiring and burning more CO_2 into the atmosphere than it sequestered; and indeed, due to the fires of the 2010s, the Amazon as a whole registered as a source of the gas for several years.[300] These were straws in the wind. Even if deforestation were to be terminated – and after Bolsonaro, Lula made some gestures in that direction – continued rise in temperatures will further reduce incoming rainfall and send heatwaves through the forest and pave the way for fires.[301] Major droughts such as those of the early century might happen in nine years out of ten by 2060.[302] Such conditions of extreme, near-permanent drought would be able to kill the rainforest of its own accord, regardless of contributions from deforestation.[303] In 2024, more than a year into the second Lula presidency, the Amazon was still in the throes of a drought worse than any previously documented: tributaries of the river drying out, carcasses of dolphins floating in overheated water, shimmering layers of dead fish, riverine communities marooned; temperatures 6°C above normal; a sandstorm in the heart of the rainforest; the by now usual wildfires; and a scientist reporting

fields of sand dunes rising out of the river – 'Sahara on the Amazon'.[304] The event was directly attributed to global warming.[305] Fears over the Amazon standing right on its tipping point trickled into the press of the Anglo-American metropoles.[306]

If the Amazon is the jewel, the crown of forests extends across the continents, and everywhere it faces a similar set of pressures: heat, drought, fire, storm, insects and pests, deforestation and depleted monocultures. Forests have always undergone natural disturbances. These are the travails of life, hitting with some frequency and size and severity: an outbreak of bark beetles, a season of windthrows, after which the forest sprouts again. But in a rapidly warming world, the regimes of disturbances are on the move.[307] Rising temperatures weaken the defences against them: consider a northern forest in which spring comes one day earlier for every year. The snow melts one day earlier, then one day earlier again. Heatwaves begin to roll through the summer and rains withhold themselves, until the forest rustles like newspaper. Potential energy is amassed in the system: then lightning strikes. It ignites a blaze and blows out the pressures accreted over time so that the forest literally goes up in smoke. In the second-generation models of self-organised criticality, none was more popular than the forest fire; and developments in much of the world's forests in the early twenty-first century fit it remarkably well.[308] Other disturbances enter the same dynamics, as when a forest debilitated by stress from heat and drought is struck down with a fungal disease and morphs into some impoverished version of an ecosystem, a basin of attraction no longer resembling the forest it has been.[309]

Fire is the emblematic element of the tipping. It has become a mainstay of the newsfeed, so normalised as to elicit little surprise. To take but one recent example: in June 2023, a massive smoke cloud from Canada's worst wildfires on record first smothered New York City and then drifted across the Atlantic, planting itself over much of Europe as a reminder to the main perpetrators of the damage being done (which is not to say that it registered as such).[310] Sometimes the smoke bellows forward from Siberia, at other times from North America, seemingly every summer from Europe itself. Anecdotal evidence from random news consumption is backed up by satellites and other instruments of observation: since the 1980s, hot and dry weather has made fires more frequent, more intense, more extensive in

virtually all corners of the globe.[311] If the warming continues, this will only get worse. The causal link is flinty. ‘Climate change is exerting a pervasive upwards pressure on fire activity globally through its impact on fire weather, and this upward pressure will escalate with each increment of global warming,’ but not in a pattern of gradual change – rather, a rising curve of ruptures.[312] As much as in the Amazon, fires in Australia or Alaska have the potential to tip forest into non-forest by damaging roots and destroying banks of seeds and buds and stripping trees of their ability to resprout.[313] Droughts can likewise provoke reorganisation of sylvan ecosystems. Species with less need for moisture will take over. Groves turn to scrub.[314]

Next after the Amazon, the subsystem of greatest concern is the boreal biome of the northern hemisphere, another sizable carbon sink, with a tendency to flip between three basins of attraction: thick taiga, open woodland, treeless tundra and steppe. Intermediate tree covers represent ‘unstable states where the system dwells only transiently’.[315] These are the saddles from which it falls into one basin or the other. Under the pressure of fire, boreal forests may plunge sharply into the frigid equivalent of the savanna.[316] But the heat might also accomplish this without the assistance of fire. The Siberian larch, a foundation species of the boreal forests of Eurasia, has a thermal tolerance threshold: there is only so much heat it can take before tissues die and the photosynthetic apparatus crumbles, and this can happen within ‘seconds to minutes following heat exposure’, and if business-as-usual continues, the nodal line is poised to be crossed around 2050 – and then there would be ‘regional-scale forest mortality on timescales of days to years’.[317] Taiga of larch, and birch and elm and aspen, would wither into something like a prairie. (Earlier estimates said 4°C, end of the century.)[318] A switch from sink to source, heralding the transition to treelessness, appeared to be in progress across the region. A full third of the ‘Arctic-Boreal’ zone had already completed it; if one also took wildfires into account, that zone as a whole ceased being a sink sometime in the early 2020s.[319] It was further testament to the anti-gradualist power of fire: during said summer of 2023, blazes in Canadian forests released three times more CO_2 than that country’s economy did in a year.[320] As for North America in general, ‘even modest climate change may lead to major

transitions in boreal forests', to quote one headline from *Nature* in 2022.[321] Even modest, lead to major: syntax of the day.

Norwegian spruce and other conifers dominate forests in the Alps. But if warming reaches 2°C, they will be driven out by smaller, broadleaved trees thriving in the warmth. These colonisers will not give the land back. Even if the temperature rise were to be annulled and alpine chill restored, the spruce would be locked out from the hills by the newer occupants, unable to disperse their seeds and return – a hysteresis with a millennium to go.[322] In southern Portugal, fires have already transformed forests of cork oak to plains of shrub and grass.[323] Some tropical forests in central Africa stand on the verge of a rainfall regime that favours savannas; small pushes might be enough to shove them over to the other side, and carbon losses have already been detected from inside the steamy rainforests of the Congo, albeit smaller and later than in the Amazon.[324] Mangrove forests have their own type of nodal line. If sea level rise exceeds six millimetres per year, they will start to undergo submergence – drown, simply put – and business-as-usual is likely to generate such a rate sometime between 2030 and 2040, on conservative assumptions.[325] Wherever one cares to look, forests are moving towards criticality.

Two implications follow for carbon dioxide removal, to be explored further below. First, the last chance for these ecosystems – the Amazon, not the least – might be massive programmes of reforestation. If deforested margins were afforested, the land could spring back to a more luxuriant life: and by the same measure, CO_2 would be drawn down. Salvaging forests would in itself be a removal technique. Second, however, the vulnerability of trees to the pressures of warming makes them brittle branches to sit on. It would be unwise to rely on lamps over the rainforest as a negative emissions technology, if that same rainforest is about to collapse into savanna. Similar liabilities pertain to all schemes for utilising forests (and indeed most other ecosystems) to absorb CO_2 in a warming world, because the warming is beckoning that gas out of them. Removal may not be able to count on their services. If it is to resurrect the dead, it needs to attach itself to something other than the dying.

Cascading slides

The subsystems possess autonomous temporalities. If the West Antarctic ice sheet has a nodal line somewhere between 1°C and 1.5°C, the neighbouring East can still have one at 8°C. But the autonomy is only ever relative. The earth's climate is a totality of many interlinked and interpenetrating totalities: if one falls, others might go down as well. Everything influences everything else, in another classic principle of dialectics; much as the downfall of the south-eastern Amazon could propagate into other parts of the forest, tipping element A can link up with B ostensibly far away. From this follows the possibility of cascading dynamics, often likened to the fall of a domino. One subsystem tips and knocks over the next in line, which in turn pushes the next closer to its nodal line, and so on.[326] Greenland is often singled out as the first domino or 'initiator of cascades': if it starts crashing into the sea, AMOC will follow.[327] But Greenland is also subject to remote influences – for instance, smoke from wildfires in the boreal band depositing layers of soot on the ice sheet, darkening its surface, reducing the albedo and speeding up the melt.[328] Any warming of the Arctic region, including a switch to ice-free summers, has, as we have seen, much the same effect.

Now if Greenland goes down, AMOC might well topple dominoes farther afield: it would leave more heat lapping against Antarctica. It would dislodge the seasonal monsoon from the Amazon.[329] Chain reactions of this kind do not necessarily require that any one component undergoes complete collapse: accelerated melting of Greenland is enough to slow down AMOC, which is enough to transmit disturbances around the globe – the circulation serving as a courier and mediator of cascades, raising, for instance, the pressure on the Amazon.[330] And if the Amazon dries up or burns out, teleconnections would propagate the disruptions to weather systems as far away as in the Himalayas, where the snow pack might be poked downhill.[331] Not all cascades take the form of one-way dominoes: some are two-way recursions, such as when a melting Greenland sends higher seas to corrode the shelves of Antarctica, and vice versa.[332] And when the seas rise fast enough, the mangrove forests decompose and their carbon is released with them, and if such feedback loops from the sinks-turned-sources are included – none larger than the permafrost – there is no telling where this spiral might stop.

All notions of linear causality here founder. The worst-case scenario, described in one of the most cited papers of climate science in recent decades, is that of slides and avalanches linking up, perhaps after a pulse of carbon from a megafire, into one meta-loop of biophysical feedback mechanisms that bids farewell to human emissions and fuels and refuels itself and continues the journey *suo motu* into a 'hothouse Earth', where the warming could transgress the nodal lines of most living things.[333]

Breaks! Breaks! Breaks!

The First World War has been adduced as a prime example of self-organised criticality.[334] A bullet fired in Sarajevo on 28 June 1914 kindled the contradictions of capitalism in its imperialist stage. When the war had broken out and the social-democratic parties betrayed their vow to solidarity, Lenin, dejected and infuriated, retreated into a Swiss library to study Hegel's *Science of Logic*. The passage that excited him most was the one about temperature and the states of water. In the margin, he scribbled: 'Breaks in gradualness. Leaps! Leaps! Leaps!'; impressed by the polemics against *natura non facit saltum*, he jotted down that 'gradualness explains nothing without leaps.'[335] Between August and December of 1914, Lenin appears to have been mesmerised by the anti-gradualist philosophy in *The Science*. Outside the library, the Ur-catastrophe of the twentieth century took on its own runaway momentum, and it was 'in this context of generalised apocalypse', as observed by Stathis Kouvelakis, that Lenin found it worthwhile to immerse himself in the basics of causality.[336] One text that flowed from his pen during these months was an encyclopaedia entry on Marx, in which he welcomed the broad acceptance of the idea of evolution, but complained that its mainstream edition was poorer than the dialectical rendition derived from Hegel:

> A development, so to speak, that proceeds in spirals, not in a straight line; a development by leaps, catastrophes, and revolutions; 'breaks in continuity'; the transformation of quantity into quality; inner impulses towards development, imparted by the contradiction and conflict of the various forces and tendencies acting on a given body, or within a given phenomenon, or within a given society; the interdependence and the closest and indissoluble connection between *all* aspects of any phenomenon (history constantly revealing ever new aspects); a connection that provides a uniform, and universal process of motion, one that follows definite laws – these are

> some of the features of dialectics as a doctrine of development that is richer than the conventional one.[337]

'The key word here is surely "catastrophe",' ventures Kouvelakis.[338] This seems accurate. Lenin reiterated that development tends to proceed 'via catastrophes and revolutions in nature and in society'.[339] If he deviated from Engels in his readings of Hegel during the autumn of 1914, it was in his alertness to the logic of catastrophe adumbrated in the central passages.[340] Engels deplored environmental degradation and considered the distant prospect of the death of the sun, to which he took a zen attitude; but the term 'catastrophe' or its cognates appear nowhere in *Dialectics of Nature*.[341] (Nor, in fact, do they appear in *Science of Logic*.)[342] Only with Lenin did this become a pivotal category of Marxist thought – a result, of course, of the First World War itself.

It would be over the top to claim that contemporary climate science is moving towards an objectively Leninist understanding of its object. But not by much. The march of this science has indeed been one long awakening – far too slow and gradual for comfort – to the dialectics of disaster, and it ends up in conspicuous proximity to the tradition running from Hegel to Lenin and beyond. Climate scientists never say this. Whether out of inhibition or ignorance, we cannot know. Already Engels noticed that practising natural scientists tend to shy away from philosophy and profess innocence of it.[343] But the evidence for the dialectics of climate catastrophe is perhaps all the richer for this presumed neutrality, since it cannot be tarnished with the suspicion of bias from card-carrying believers in 'diamat': it is strictly empirical work that has forced this science to keep washing away its gradualist and mechanist leftovers. The breakthroughs of Lewontin, Gould et al. opened up a conceptual space for seeing the dynamics; but it would be too much to say that post-gradualist climate science is a derivative of the Black Panther Party or Science for the People. It has furnished a richness of insights into the actual dialectics of disaster far beyond anything found in the original 'laws'; yet it is this same richness that accords them such resounding confirmation. This is no solace. There is no reason for celebration or self-satisfaction here. The convergence between climate science and Hegelian–Leninian dialectics *is* the catastrophe. It would obviously be much nicer to live in a social-democratic, evolutionary,

reformist world in which social and natural systems are re-engineered by increment. Alas, we do not.

For Lenin, the answer to catastrophe was, of course, revolution, the two categories reflections of each other in their causal forms, manifesting – negatively, positively – the way things can eventually rupture. Against the inevitable breaks, he advanced intentional leaps. Indeed, the deepest rationale for the revolution was to stop the catastrophe engulfing Russia and Europe and the rest of the world in its tracks, to intervene before it was too late to avoid a headlong plunge into the abyss: after 1914, Lenin became the theorist and practitioner of urgency and stress.[344] A quantity-quality leap was imperative to avert further quantity-quality breaks, and the same formula applies to the climate. The near future we are looking at, in other words, is the following. *It is because humanity failed to leap out of fossil capital in time that breaks in the climate system proliferate*.[345] The ubiquity of avalanches in nature is a function of the avalanche that did not happen in society before it was too late. Such a causal integration is something new in history: never before has the absence of revolution engendered catastrophe from pole to pole, and in this sense, by combining the positive moment in its negation and the negative moment in its excess, climate breakdown is 'the proof of dialectics', as Engels held nature to be.[346] It settles the dispute within Marxism over whether dialectics exists only in society or in nature too.[347]

Climate breakdown, put differently, is the collision between a society that cannot bring itself to change course and a nature that cannot withstand the resultant pressure. The world we live in is Gouldian and Leninian: there is either stasis or punctuation; or, rather, there are so many punctuations in nature because society remains stuck in such excruciating stasis, as it shoots forth like a projectile against the most delicate target, the forward motion itself a kind of inertia; there is so much catastrophe because the revolution that should have taken place still has not. If Alexander Herzen labelled Hegel's dialectic 'the algebra of revolution', Lenin intuited that it was the algebra of *both* catastrophe and revolution; after the revolution that never was, the algebra of catastrophe is what remains. It unfolds through the multiplication of the original signal in the form of slides. They follow a homologous logic on every scale. A glacial lake bursts like an ice shelf fractures and a rainforest the size of half a continent flips into savanna. Extreme weather events – wildfires, landslides, heatwaves above the wet-

bulb temperature of 35°C – obey the same principles, as would the cascading disasters in a hothouse Earth.[348] We get slides and avalanches small and large, effectuated in seconds or decades or much longer. Whether we zoom in or out, they look virtually the same: in self-organised criticality, they exhibit ‘scale invariance’ or ‘self-similarity’ or, perhaps best, a fractal pattern.[349] All flows from the balance of the opposing forces of insolation and re-radiation having been upset by the accumulation of CO_2 in the atmosphere, which fills the biosphere with a surplus of energy, which gets distributed throughout the subsystems and intensifies contradictions inside them, until the breaks begin and a spiral sets forth and one component after another turns into its opposite: ice becomes water, circulation a standstill, solid matter gaseous air, damp forest dryland.

Inevitably, the age of avalanches enters (some level of) popular consciousness, as the events keep crashing into daily life. While the fires engulfed Los Angeles in January 2025, the *New York Times* surveyed the science and announced ‘a dangerous new era’ for life on this planet. In demotic idiom, it attributed the recent scenes to the by now recognisable dialectics: following abnormally high temperatures in California, ‘many of the plants that grew last year are parched, turning trees, grasses and bushes into kindling that was ready to explode’. The critical combination of heat and dryness ‘created the ideal conditions for an urban firestorm’. Dialectics on the downside becomes direct experience. Every local disaster forms a monad of the era: the *Times* listed the trends of hotter and faster wildfires, bigger and heavier storms, heat waves and droughts ‘which can be devastating on their own and leave communities vulnerable to dangers like mudslides when heavy rains return’, the slides morphologically refracting one another.[350] Ten days after that report, Trump was reinaugurated like the tsar of an everlasting dynasty, seemingly ensuring the irresistible drive towards a future of rubble heaps.

But it might yet be too early to make such bleak pronouncements. Perhaps a minute remains for the revolution. A society – even a late-late-late capitalist society – might turn out to be a sandpile too. When least expected, an *iskra* could set things aflame. Lenin would never accept the solidity of the status quo as a given, and no sooner had researchers like Lenton discovered tipping points in the climate system than they expanded their agenda into politics and concluded that similar points exist in society –

a presentable revival of the catastrophe/revolution couplet. We shall return to the conditions and prospects for social tipping in the final pages of this book. It implies the possibility of agents rising up in time to prevent the activation of the points in climate.[351] When would this need to eventuate? This is another way to phrase the question of the cluster. We have seen the best current estimates place the nodal line for Greenland at 1.6°C, for the West Antarctic ice sheet at between 1°C and 1.5°C, the East in the vicinity of 8°C to 10°C, AMOC between 1.4°C and 2.2°C, the permafrost around 1.5°C, the Amazon thereabouts too. The cluster forms around a global *knotenlinie* of 1.5°C or, in a better case, 2°C.[352] The urgency and stress could hardly be greater. 'The intervention time left to prevent tipping could already have shrunk towards zero,' in one assessment from Lenton et al., in 2019.[353] Lenin has now long since left the library in haste and taken the first train back to Petrograd.

Heads in the sand

We can now begin to see just how cruel the prescription of overshoot-and-return is. The crucial zone between 1.5°C and 2°C is populated by nodal lines the crossing of which would have effects that might not be possible to wind back on a timescale meaningful to humans. The recommendation to enter that zone and perhaps go even further and then retreat to the starting line by means of negative emissions technologies is rather like ordering a group of school children to dash through a field packed with landmines and come back.[354] Even a temporary excursion increases the risks significantly, including for cascades.[355] It *might* turn out relatively fine – only a few limbs lost.[356] Or we might, while in the zone, find that bombs are going off all over it. A precautionary principle normally regarded as basic rationality would have deemed 1.5°C an upper, outer limit and banned forays beyond it – 'you wouldn't build a bridge or a nuclear power plant that has a two per cent chance of collapsing or blowing up,' in the words of one prominent climate scientist, here considering the risks for AMOC.[357] But when it comes to climate, all caution and rationality are thrown to the wind. The sixth assessment report from the IPCC included clear warnings about the hazards of overshoot; but in the 'summary for policy-makers' read by that

important audience, representatives of governments had those warnings 'diluted or deleted', as they would sap the credibility of removal and intimate the need for something more like revolution.[358] Actual emissions trajectories in place at this point were taking the world towards 3°C in the twenty-first century (and with feedbacks poorly represented, this might well be a lower bound).[359]

Removal is an attempt to make up for the revolution that did not happen. To do this, it clings – arguably even in its benevolent guises of 'restoration' – to a gradualist and mechanistic view of the climate system, despite all the dialectical conclusions of the science. For removal to stay credible, its architects must keep the ideology of the earth-machine alive and stick their heads in the sand, like Lyell and Darwin when confronted with damning evidence: they must belittle the danger of tipping points. One article, honestly entitled 'Emit Now, Mitigate Later?', put this method on full display.[360] A group of Norwegian researchers recognised the challenge posed to the project of removal and designed six overshoot simulations in a computer model to test it. All spanned 400 years. At varying speed, they cranked up the CO_2 concentration, then levelled it out, then brought it back down again by means of DAC. At the end of the exercise, most parameters of significance in the climate system were reversed to their baselines. The earth had been renovated. 'We do not find evidence for large-scale self-amplifying feedbacks or abrupt shifts that would indicate that a tipping point has been crossed during the overshoot periods in our model simulations.'[361] How could such an auspicious absence be found? By the authors simply omitting tipping points from their model. No abrupt thawing of the permafrost was uncovered, because none was admitted entry into any of the simulations. No tipping of the Amazon was registered 'even after the most extreme overshoot'; the woodlands of the world remained stable over four centuries of maximising and then taking out CO_2, because they were assumed to have undergone no deforestation since the nineteenth century – history unmodelled – and so on.[362] The answer – yes, the climate system evinces near-perfect reversibility – was given already in the question put to the computer.

That was not an exceptional methodological choice. 'We see no evidence of critical thresholds in these simulations,' reported a second team likewise concluding on reversibility. How could no such evidence be found? 'Some

processes, such as permafrost processes, ice sheets and glacier dynamics', the team acknowledged, 'are not or only partly included in the model, although it is recognised that they could play a role in reversibility issues.'[363] Another team went back to the IAM of William Nordhaus and performed another few model runs and found that 'social welfare' is 'unambiguously increasing with later compliance date' – people will be better off, that is, if the date for cuts is postponed and the intervening emissions revoked by removal.[364] No tipping points could make the finding a little ambiguous, because none were authorised to show up inside the model. This was the best if not the sole way to design the time machine.

Sisyphus rolls down the carbon

Any tipping point would rip up the equivalence between one gigatonne of positive and one of negative emissions, and so would another, somewhat less spectacular logic of the climate totality. Once it escapes chimneys and exhaust pipes, CO_2 is dispersed in the air. But what goes up comes down: the atmosphere inhales and exhales in a constant exchange with terrestrial spheres. Upon release into the air, the CO_2 is slowly cycled through finely balanced circuits looping through ocean, rock, soil, forest, every other kind of vegetation and living thing, each connected to the rest. Like communicating vessels, the atmosphere and its opposite spheres siphon the gas between them until a new equilibrium is reached – pour carbon into one and before long it will disseminate through the others as well. So far, this has worked to our advantage, buffering, in a manner of speaking, humanity against its sins. The atmosphere has been flooded with CO_2 from the underground stock, but the sinks of the earth have mopped up much of it. About half of emissions have been reabsorbed by oceans and forests, divided roughly equally between them.[365] In a moving, dynamic equilibrium, two centuries of fossil fuel combustion have supercharged the carbon cycle, leaving the sinks brimming with the gas while keeping atmospheric concentrations – and hence temperatures – far lower than they would otherwise have been.

What happens, then, if humans start actively removing CO_2 from the atmosphere? In this hypothetical future, the air would be relieved of some of the gas poured into it. But then the terrestrial spheres would have less reason to keep so much inside of them. To make this a little more concrete: CO_2 dissolves in contact with water and forms a compound everyone has felt crackling in the palate: carbonic acid. The level of gas in the water is proportional to its pressure from above. In the contemporary encounter between ever-more CO_2-heavy atmosphere and oceans, there is a transfer from the former into the latter, most intense when high waves lick the gas from the air. The more CO_2 the air holds, the more the oceans will swallow. If the air has held much of it for a long time, the oceans will eventually also be full: but if it were to lose some of its gas content, they would respond in kind. The oceans would burp the carbon back, as the two spheres move towards a new equilibrium (CO_2 always wants to flow from where it is highly concentrated to where it is not). Removal would set off a process of *outgassing*, from oceans and forests and other spheres: sinks would somersault into sources. 'The temporary balance of opposing forces', to speak again with Levins and Lewontin, would turn upside down, the buffer becoming an outflux, just as and *because* humanity wipes away CO_2 from the atmosphere. The more that is removed, the more will be outgassed; the faster the take-out, the faster the replenishment.[366] *The more that is removed, the more must be removed*, lending this project, too, a Sisyphean character. The more effective it is, the more of the weight of the carbon amassed in the various spheres on Earth will fall back on it.

A removal project could not, in other words, aim only at the sum of CO_2 parked in the atmosphere, mercifully reduced by the sinks on Earth. It would have to prepare to take on the subtracted sum too. That would not capsize the arithmetic as such – it would still be one gigatonne in, one out – but the boundaries of the equation would now include the original gigatonnes that passed through the atmosphere en route to the seas or trees. One study pondered what would happen if the CO_2 concentration reaches 511 ppm by mid-century and then humanity pulls off a splendidly enormous removal. All of the gas accumulated in the atmosphere is drawn down in one go. The concentration drops to 280 ppm, the pre-industrial baseline. That would be a truly Herculean achievement. But over the next three

decades, the concentration would then rebound by nearly one third, due to outgassing. As if the initial achievement were not enough, the removal would have to continue to fight itself back to the baseline again and again.[367] This is an idealised scenario, which holds three hard lessons for removal. First, starting to draw down CO_2 from the atmosphere entails a commitment to also do so from other spheres. Second, the better the project works, the greater the challenges to it. Third, the size of the infrastructure marshalled for the task would have to be massive – an understatement – if the feedbacks coming against it are to be defeated.

The end of equivalence

But not only removal would summon back CO_2: so would the prior warming itself. We have seen how major pools are beginning to lose their capacity to keep the gas under guard. It is slipping out of the permafrost and the Amazon and every other forest that burns. If the gates from the permafrost, say, would be thrown wide open, the atmosphere would be flooded with an additional mega-flux and the removal assignment made doubly or quadruply difficult – a type of add-on flowing from several tipping points. In its normal mode, AMOC operates as the northern hemisphere's largest carbon sink, its cold, salty waters slurping carbon out of the air and sending half a gigatonne of it to the bottoms every year. Sabotage the circulation and the crates of carbonic acid will sink no more.[368] Then there are also slowly working – yes, gradual – processes weakening the sinks: warm waters are not so good at pumping down CO_2, as we saw in the context of glacial cycles, and the warmer they become, the more prone they will be to leaking the fizz, and nowhere do they warm as fast as in northern latitudes, where the sink has hitherto worked hardest. When the oceans are supercharged with CO_2, the ability of the chemical pump to take down more of it eventually tapers off. Another word for such supercharging is, of course, acidification: and the lower the pH falls, the harder it becomes for organisms ranging from plankton to corals to form shells and skeletons and the more liable they are to dissolution in the acid

seas. Marine photosynthesis wanes. The biological pump downs its tools too.[369]

Analogous processes are underway in the *terra firma* sinks, where the biological pump – often referred to as the 'CO_2 fertilisation effect' – has been working overtime. More CO_2 in the atmosphere puts photosynthesis on steroids – up to a certain level. Plants cannot grow forever. They do not have infinite space to expand in, whereas the atmosphere can fill up with CO_2 for as long as there is air. When the vegetation is saturated, there is more than enough of the raw material at hand, and then one extra dose of CO_2 no longer promotes production; a shortage of other inputs – water, shade, coolness, nutrients – will rather constrain it.[370] For these reasons, the fertilisation effect weakened during the four decades around the turn of the millennium.[371] Tropical forests hit peak absorption in the 1990s and have since shouldered less of the burden.[372] Wildfires in Indonesia in 1997 – draping much of Southeast Asia in grey ash – and a heatwave in Europe in 2003 – the yellowing of the continent visible from space – were early omens of the release.[373] Concerned scientists saw the land sink of the northern hemisphere getting feebler over the 2010s. Nothing could quite prepare them, however, for what happened in 2023. The atmospheric CO_2 as measured at the Mauna Loa observatory jumped by 3.4 ppm in a single year. The average over the past decade had been 2.4 ppm – itself a dizzying growth rate, now suddenly higher by nearly one half. What explained the leap? Emissions from fossil fuel combustion continued to grow, by about one per cent, as we have seen; but that was a minor piece of the puzzle. The main cause was the crisis in the earth's forests: the fires in Canada, the drought in the Amazon, boreal and tropical woodlands not absorbing but venting the gas. The preeminent observers officially announced 'the cancellation of the global land sink in 2023'.[374] Land no longer reliably sucked out CO_2.

If fire and drought were the main mechanisms for igniting this collapse, others could be made out on the horizon. Heat itself is one. Come the early 2020s and scientists announced the approach of yet another tipping point, beyond which temperatures are so high that plants effectively go on strike: photosynthesis declines exponentially, respiration increases equally exponentially, the metabolic process is inverted and CO_2 spewed out of

forests from Canada to Cambodia. Business-as-usual will transgress this nodal line around 2040. This would in itself signal the loss of the main land sink – 'a formidable positive climatic feedback'.[375] (And to this comes another cause for concern: trees that have taken high CO_2 levels appear to grow fast and die young, rather like athletes who have used steroids. A generation of loaded trees on Earth would then be in for premature death. The land sink would be filled with 'necromass pools'.[376]) Soils, peatlands: same story, same loss of absorptive powers under heat and drought, the valves instead opened for the carbon to run away.[377] There is, in short, only so much of the element you can stuff into the system before things start to break.[378]

Early climate science expected the opposite. One reason for Arrhenius being so unperturbed by CO_2 emissions was that he counted on oceans to tuck away more than four fifths of them.[379] Scientists who did not worry much pointed to the fertilisation effect as late as in the 1990s.[380] As if the earth were a machine engineered with the latest control theory or just a simple steam engine with pistons moving up and down, negative feedbacks were supposed to stabilise the climate. When this belief was eventually punctured, the science still struggled to move beyond linear causality: emissions grow by X → the greenhouse effect is enhanced by Y → temperatures rise by Z. But in the real world, temperatures curve back on emissions. Causality 'goes two ways', in the words of some of the scientists seeking to break the line in the early millennium and replace it with default undeclared dialectics.[381] ('*Reciprocity of action* is', in the words of Hegel, 'only causality itself; the cause does not just *have* an effect but, in the effect, refers *as cause* back to itself.')[382] Everything is now connected in a spiral of blooming decay.

Even before the turning point of 2023, observations burrowed through the walls of gradualism: fossil fuel combustion yields a tendency for the capacity of sinks to fall.[383] They are ceasing their work of salvation and instead contributing to the curse. Linearity is not, after all, a feature of the climate system. Its sensitivity to a given quantum of emissions is so much higher if feedback mechanisms are included – so much indeed that, in early 2025, a team of scientists at the Potsdam Institute claimed that the cumulative emissions piled on top of each other until that point might possibly be realised as a rise in average temperatures by *three degrees*. An

expected warming by 3°C towards the end of the century might rather come in as 6°C. And then this study had not included some of the most potent feedback mechanisms – an end to CO_2 fertilisation, a non-gradual thawing of the permafrost, the methane hydrates activated – while, from a university in the antipodes, researchers warned that recent wildfire seasons might already be pushing the earth onto the trajectory of the hothouse.[384] Needless to say, this would render the problem of outgassing moot. If the sinks collapse under the pressure of the airborne fraction of CO_2 – if, that is, 2023 was just the beginning – they won't hold very much of the gas for later.[385] But then again hothouse Earth would render everything moot. Let us fight shy of that scenario and assume it won't come true. Merely suppose, for the time being, that some amount of feedback mechanisms do add CO_2 to the atmosphere from the lands and seas. How could negative emissions technologies possibly recapture it?

The more sinks have weakened and turned to sources, the more CO_2 must be drawn down for climate to be restored to where it was: for every gigatonne that was emitted, perhaps one and a half or two must be removed if its effect is to be cancelled out. It takes more of the negative to beat the positive. The equivalence ends, and the asymmetry *increases with the magnitude emitted*, so that the same problem that makes removal appear necessary also makes it seem well-nigh impossible.[386] It has proven remarkably easy for capitalist society to emit CO_2 that will in turn make more CO_2 ooze out from the earth. It will not be as easy to deploy technologies to dial back both processes: they would have to form an apparatus as impactful as the entirety of fossil capital over the *longue durée* and then some. And then we have not even summed up all the research suggesting that *even if* all the carbon were conclusively swept away from every sphere, the slowly churning oceans will continue to process and store and release the heat itself for a long time: after all positive emissions have been negated, there would still be more heat in the pipeline, so strong is the hysteresis, and that heat would itself renew the efflux of carbon from within the oceans.[387] Somewhere around here, an appeal to negative emissions begins to look rather like an appeal to magic.

War on the rollercoaster

Suppose it does work. Suppose average increase in temperature on Earth hits 2°C and then falls back to 1.5°C three decades later. As magical as the achievement would be, it will not bring back to life the children crushed by a glacial-lake-outburst flood in a Peruvian valley.[388] For a farmer in Sudan whose livestock perishes in a heatwave that would have been avoided at 1.5°C, it will be scant consolation to know that temperatures are scheduled to return to that level when her children have grown up. Even *if* the thermostat is successfully turned down, the damages from the period of overshoot will not be abrogated – the lives lost, the livelihoods wrecked, the lands laid to waste; and as usual, such damages will be concentrated to the global South.[389] Overshoot-and-return can never equal avoidance. In between there will be that thing called history, which no time machine can evaporate, and history is not reducible to the terminus of a mechanical operation.[390] It is more than an endpoint.

To plan history this way – and overshoot-and-return aspires to do just that – would, furthermore, be to ask generations to board a rollercoaster. First, they would have to learn to live with peak heat. They would have to adapt as best they can to all the extremes around 2°C, living for years and maybe decades on the precipice: fields relocated to tolerable climes, stress-tolerant crops planted, buildings moved out of harm's way.[391] Entire societal functions would need to be adjusted to the temperature maximum. Then, as the rollercoaster dips down, they would need to be readjusted in the opposite direction. Perhaps agriculture has been shifted north – and now that northern latitudes revert to being less conducive to food production, the whole enterprise must shift south again. Overshoot-and-return would double the trials of adaptation. Given what we know from that frontline of climate politics, it will not be a smooth ride. Instead, the battlefields will multiply all over again.

Some travellers on this rollercoaster might, moreover, have to sit in bungee-jumping seats attached to it.[392] We know that warming is amplified in the Arctic. With the albedo feedback put in reverse gear, removal would cause a correspondingly steeper temperature drop in the region. Now assume this happens while AMOC is locked in hysteretic weakness or standstill. The cooling would not be watered down through southward

transport. Removal, in other words, would risk super-freezing the far north in relation to the rest of the planet. But then things might turn the other way if AMOC comes alive again.[393] After decades of stagnation, a surfeit of heat will have built up along the equator. Now if the circulation restarts, it will have a lot of heat to shuffle away and so might go into overdrive and generate an 'extended period of anomalously strong northward heat transport': the north warming up as sharply as it recently cooled down.[394] How would people in the Arctic cope with these oscillations?

If this scenario is realised, there would be a 'thaw–refreeze–rethaw cycle' playing out over decades or even a couple of centuries. Arctic communities would first need to adapt to rapidly disappearing ice (thaw). During this phase, they would see ecosystems greening, buildings collapsing over thawing permafrost, towns replanned and perhaps invented anew. Imagine doing this for a few decades, as the ice recedes: and then removal sets in while AMOC is down, and temperatures fall again and the ice returns (refreeze). In the next phase, AMOC starts recovering, heat flows in, temperatures rise, the ice vanishes once more (rethaw) – it would be disarray upon disarray. This bungee-jumping from the rollercoaster would not just include the Arctic, but other parts of the northern hemisphere as well, though to a less extreme degree. But the problem would not merely be the serial concussions inflicted on communities. Insofar as adaptation in any phase is reasonably effective, and insofar as society remains recognisably capitalist, *there will be vested interests in extending that phase for some time more*.

Treasure hunters are currently streaming into the warming and melting Arctic. They are looking for deposits of gold and rare-earth elements, cobalt and nickel, coal and gas; mining has become a realistic option, sometimes facilitated by nuclear-powered icebreakers. They are opening shipping lanes where the ice used to be unshakable. They include Jeff Bezos and Elon Musk, Russian and Chinese corporations, Emirati and Norwegian firms, capitalists of all stripes flocking to the frontier of thaw.[395] Suppose these conditions do in fact usher in sources of profit, even gold rushes. And now the Arctic is slated to refreeze, because removal is about to commence: will the capitalists invested in the ice-free region abide this? Fixed capital of not-insignificant quantities might have been sunk in the thawed grounds. It does not require a wild imagination to expect that interests will be mobilised *against* removal, if indeed it sends the region away from a

climate exploited at a profit. And this would seem to apply to each phase in the thaw–refreeze–rethaw cycle and any other moment of overshoot-and-return, in the Arctic as elsewhere: *lucrative adaptation to one temperature regime will bequeath reluctance to shift to the next* – each status quo, however temporary, defended by at least some actors. Against them would stand, one can imagine, populations keen on returning to homelands from which they have been displaced by the heat.

We can then look forward to decades of international negotiations and summits on the manipulation of the thermostat. An initial promise to keep overshoot low and brief might be broken, exceptions and compromises written into agreements. Will the commitment to return to 1.5°C survive? Summit succeeding tedious summit while the overshoot period is extended in the name of cost effectiveness does not appear a far-fetched scenario. It would be more of the world as we know it. If overshoot-and-return does prove feasible, it would open a new chapter in a well-worn book, another round of clashing over mitigation, adaptation, removal – not a solution, but a battleground folded into the future. The better overshoot-and-return works, the more fights over it there will be.

Seasons of migration to the north and back

Other organisms than human beings would be subject to similar treatment. Some species and ecosystems might be wiped out entirely by the world – however temporarily – blowing past 1.5°C. No amount of removal would bring them back once the last individual has keeled over. Extinction is a brick wall of finality, harder than death. There can be no firmer proof of irreversibility (barring technologies for de-extinction).[396] And already before 1.5°C, global warming had mowed down animals: in the recurring Australian heatwaves, thousands of flying foxes died every year because they could no longer cool their bodies. When temperatures around Cairns in the north-east of the country soared to 42°C for two days in 2018 – a full 5°C higher than the previous record for the area – up to a third of one species, the spectacled flying fox, expired. After such ‘mass mortality events’, aggravated by wildfires, charred carcasses of bats littered the dry grounds.[397] Birds falling out of the sky meet lay criteria for signs of the

apocalypse.[398] In a migratory corridor stretching from Nebraska to New Mexico, thousands of birds dropped dead in 2020. Wildfires and drought had left them emaciated and exhausted.[399] When temperatures hovered above 40°C for days on end in large parts of normally temperate British Colombia in the summer of 2021, an estimated one billion sea creatures died, the heat literally cooking mussels and oysters in their shells – an 'overpowering, visceral experience', reported one scientist from the stinking beaches.[400]

While local drivers of habitat destruction, notably the conversion of wild land to asphalt and plantations, have so far dominated biodiversity loss, global warming has the potential to eclipse them all. Unlike a bulldozer or bullet, it can reach into every remote little niche, even in the deep oceans.[401] When a climate to which a species is adapted leaves it marooned, the first impulse will be to track a new habitat and migrate. But there is not always an exit: many of the world's biodiversity hotspots are wrapped around mountains, on which species can follow the receding climate envelope only to the summit, a nodal line carved in stone.[402] Many others are spread over islands that could be inundated (particularly in the Caribbean).[403] If the species have the misfortune of living in a long nature-depleted country like the UK or Belgium, the routes to refugia might be intersected by highways, farms, industrial zones.[404] Meanwhile, the pressure to migrate will be unlike anything experienced by extant lineages. Whereas trees dispersed by between twenty and forty kilometres per century during recent glacial cycles, global warming will require that they sprint northwards by perhaps 500 kilometres per century, so much faster is this dislocation.[405] If an exodus is set in motion, species and populations that have co-evolved and lived in mutual dependence might fan out in different directions and run at varying speeds and lose contact with each other: communities could come undone.[406] Through these mechanisms and many others, global warming might develop into a force majeure overwhelming adaptive capacities and overtaking the evolutionary process with a change so dramatic that it cannot keep up: the selective pressure turns destructive; mass extinction ensues.[407] The idea that a cataclysmic alteration of the planetary environment could extirpate entire taxa in one blow was, of course, anathema to Darwin. Nothing so tore apart the model of gently extrapolated microevolution. But

since the days of Gould, evidence has amassed of such catastrophes occurring in the past, and of an imminent anthropogenic repetition.[408]

The causal form of this process is, once again, that of pushing things – living things, in this case – to the edge. This can happen in a moment. Already observed local extinctions have been attributed to spells of extreme heat, even where mean temperatures have not increased appreciably.[409] Absolute heat tolerance is a trait locked in by evolution – a function of physiological stasis – and as with the flying foxes of Australia, a couple of days above the inborn threshold may be enough to cause mass die-off.[410] Or stresses may be recurring, as when several consecutive hot and dry summers wear down the trees of southern Europe. Yet another summer of that kind can be fatal in a way the first was not.[411] Whether by pushing organisms over the edge through a pulse or through compounding pressure, any overshoot would raise the odds for catastrophic slides on all scales. But it is not Europe that stands to lose the most species if the world passes 2°C on its way to 1.5°C: it is the tropics.[412] We have seen what awaits the Amazon.

What we have not done is to provide an exhaustive list of tipping elements. There are also, inter alia, the methane hydrate deposits, the monsoon systems, the vegetation in the Sahel and, flagship of biodiversity, the coral reefs.[413] There has been an uncommonly long consensus about the nodal line of the latter being very near.[414] At around 1.5°C of average warming, the marine heatwaves that break the symbiosis between corals and algae and so bleach and kill the former will be too frequent for most reefs to endure. To save half of them, the upper limit would need to be 1.2°C.[415] Some enjoy refugia – lagoons, deep waters, sweet spots of upwelling or active currents – but at 1.5°C, only 0.2 per cent of such asylums can still shelter corals against the heat; at 2°C, the share falls to 0.0.[416]

For more overshoot – up to 2°C – not only the coral reefs but plenty of other marine species and ecosystems would be damned, particularly given the lag in ocean warming.[417] Alternative stable states would be rife. Species clinging to montane slopes would trek upwards, until they reach thin air, where they would be unable to sit out any exceedance of a temperature limit, however temporary – likewise for species whose abodes are submerged.[418] But those still hanging from a cliff edge might be able to

crawl back if temperatures start declining. If they have migrated into refugia now rendered less hospitable by the cooling, they would have to go back and recolonise their habitats – provided they are intact.[419] It would be seasons of migration to the north and up and then to the south and down again. On the way home, populations might bump into fresh obstacles. Perhaps humans have crossed their paths with their own installations of cyclical adaptation – a field or town established then abandoned, whatever garbage left behind.[420] It cannot be taken for granted that species surviving a period of overshoot would be able to return during the return phase. But at least they would have no capital invested in the refugia that saved them. Nor would they be able to fight for their right of return.

The tragedy of overshoot

One conclusion from all of this could be: we have got to do solar geoengineering. If it were to be deployed tomorrow, we could go back below 1.5°C to 1.3°C and 1.1°C and onwards in what would, for all practical purposes, be an instant. Nothing else enables us to effect such a cooling. Even the most fantastically successful removal would have to run for decades before temperatures fall: precious time we cannot waste. Only solar geoengineering has the requisite Leninist qualities, a storming-the-heavens temporality and attitude. Or so it would seem. We shall examine this option closely in the third part of this book.

Another possible conclusion could be: if overshoot of 1.5°C is now unpreventable, the task is to minimise its magnitude and duration. Everything will be worse if the overshoot is big and long. Everything will be less bad, or less worse, if it is small and short.[421] This is a tautology identical to the proposition that a lot of global warming is worse than a little, but it now takes on the urgency of damage control. We saw this conclusion emerge from the case of permafrost. Even for subsystems already slipping away, there is still a difference to be made: at 1.5°C, the West Antarctic Ice Sheet might (in the best case) need ten millennia to melt in toto; above 2°C, it could happen in less than one.[422] To communities on the frontlines of sea level rise, the former timetable would give a fighting chance at adapting. But given the way CO_2 keeps being poured into the

atmosphere – the bathtub constantly filling up – minimising overshoot and its damages in this way would still seem to necessitate removal. That is how the bathwater gets thrown out. We would then have come full circle to stop-and-reverse.

Such a conclusion, it is important to note, would be distinct from *programmatic* overshoot: it would not *advocate* future removal as a salve for a present that cannot bring its emissions under control. Rather, it would take stock of the situation and lucidly register that warming has become excessive. Hence emissions must be eradicated by any means necessary *and* turned negative as fast as physically possible. This would be something more like *tragic* overshoot: a realisation that the transgression of 1.5°C is taking place as we speak, and that it imposes on us precisely the negative emissions technologies we so would have liked to ignore. The tragedy could extend further into the future. If we are force-marched to 2.5°C or 3°C, how could we – those who have not already been killed, that is – possibly try and turn around, if not by means of removal? If the masters of this universe drive us out into the minefield, there really seems to be no other way back, virtually by definition (excluding, for the moment, geoengineering). The farther out we come, the more bombs that go off, the truer this would be. Overshoot-and-return might become a self-fulfilling tragedy. The false promise of removal, in its very falseness and clouded efficacy, could force us to pin some hope on it.

Is the magic trick here to dragoon us all into a belief in magic? Or is there a kernel of realism in negative emissions technologies? What would it actually take to extract CO_2 from the atmosphere: how could it be done? In what quantities, with what byproducts? By whom – who is preparing to do it, for what purposes? These are the next chapters in a preliminary study of the overshoot tragedy.

8

Browse Our New Catalogue

At the time of this writing, we are in the midst of a Cambrian explosion of negative emissions technologies. Some creations are bizarrely formed. Others look familiar. A few show signs of real viability. The explosive evolution of ideas for how to remove CO_2 is not necessarily guided by limitations and boundaries in nature. Because it forms the sequel to fossil fuel–based technologies – those that have filled the atmosphere with the gas – we should rather expect it to keep flowing through channels of irrationality. But a concrete analysis of these technologies cannot start with axioms. It should set out from their concrete manifestations, in the ever-expanding catalogue of new innovations.

Harder, better, faster, stronger

The first idea that comes to mind is to incite nature to work harder. We have seen how moments of the active carbon cycle spontaneously bring CO_2 down to Earth, as in the case of plants. They filter the molecule from the air and use sunlight to split the oxygen from the carbon and store the element in their leaves, twigs, trunks, roots. Removal is the essence of their species being. In forests and grasslands, peatlands and mangroves, it happens every second, and so the idea comes naturally: just goad them to capture more. Advocates of this approach like to argue that there is no magic involved, merely a helping hand extended to processes already at work wherever chlorophyll is found.[1] There is also a world-making historical precedent.

After European colonisers crossed the Atlantic in 1492, their guns and germs killed 55 million people in the Americas, reducing the indigenous inhabitants to 6 million, a fragment of one tenth of what it was – 'the largest human population replacement in the past 13,000 years'; and because all these people vanished from their villages and terraces and pastures, the forests thickened and advanced.[2] Plants were given free rein. The atmospheric CO_2 concentration dipped by between 7 and 10 ppm. Average temperatures on Earth fell by 0.15°C.[3] Apparently it can be done, under the right circumstances.

If the 'Great Dying' in the Americas contributed to the Little Ice Age, global warming had barely been discovered before scientists proposed treating it with herbal medicine.[4] In a notorious article from 1977, Freeman Dyson envisaged establishing 'rapid-growth plantations' of 'trees and swamp-plants' on 'marginal land in various parts of the world'.[5] The idea was soon scooped up by interested parties in Dyson's homeland, the US. By 1988, congressional hearings were held on the subject. This was the year of the heatwave and the Hansen testimony, the moment of birth for American climate politics, and the deliberate growing of forests was very much present; the idea entered the first proposed climate bills.[6] 'In the long run, it might be cheaper than a lot of other options,' one official from the Environmental Protection Agency explained the appeal.[7] In a news article headlined 'Johnny Appleseed and the Greenhouse', *Science* invoked the memory of a tree-loving white settler and quoted one scientist who had calculated that sycamores on farms the size of Australia would capture as much CO_2 as was then emitted per year. One colleague opted for the humbler ambition of covering land as large as the country still known as Zaire.[8] From this moment, the potion of billions of trees would be continuously issued from the pharmacy of American climate politics – even by Donald Trump, who rounded off his first presidency by, Melania at his side, planting a maple tree on the White House lawn and signing an executive order for 'one trillion trees'.[9]

No other idea had the same power to unite the most stubborn adversaries in the climate debate. In the case of Trump, of course, it did not even require an admission of the problem's existence; the care for 'our Nation's Forests' was patriotic.[10] On the opposite side of the aisle, a version of the idea was championed by the celebrities of radical campaigning. In 2019, at

the height of the protest wave, George Monbiot penned a manifesto for ‘natural climate solutions. This means drawing carbon dioxide out of the air by protecting and restoring ecosystems’; among the signatories were Greta Thunberg, Naomi Klein, Michael Mann, Bill McKibben.[11] Featuring Thunberg, Monbiot made a short film to accompany the manifesto and declared in solemn sincerity: ‘There is a magic machine that sucks carbon out of the air, costs very little and builds itself. It’s called … a tree.’ With his signature voice of enchantment, in front of vaguely anthropological figurines and over scenes sampled from nature movies, he waxed about ‘mangroves, peat bogs, jungles, marshes, seabeds, kelp forests, swamps, coral reefs – they take carbon out of the air and lock it away. Nature is a tool we can use to repair our broken climate.’[12] Only with this tool could the probable overshoot of 1.5°C be reversed. Monbiot stressed the cheapness of it.[13] And this was indeed the gist of ‘natural climate solutions’, a concept that came into scientific currency after an article in 2017 and proved attractive to the most diverse audiences, much like skincare appeals to a wider range of customers if it is labelled ‘natural’.[14] But what exactly would be ‘natural’ about these tools? The absence of machines, it would seem: natural climate solutions are defined by their reliance on photosynthesis, without added mechanical appliances, boosted and pimped up in other ways. But the contours of the category are fuzzy; lamps over the rainforest would be one borderline case.

A general prescription in three parts is ‘protect, manage, restore’: protect the ecosystems that naturally sequester carbon from destruction; manage them wisely; if they have already been destroyed, make sure to restore them to their full potential.[15] It is the last moment that holds the promise of drawdown. A stately old-growth forest saved from the chainsaws remains in equipoise with the atmosphere, whereas a young and hungry forest actively pulls in CO_2 when reclaiming lost land: in the Amazon, the latter type sequesters carbon up to twenty times faster than the former.[16] Massive reforestation of the south-eastern rim would thus protect the biome *and* win back carbon to the earth.[17] In a benign replication of the long sixteenth century, Latin America in general and the Brazilian Amazon in particular are held out as the locations with the greatest capacity to remove CO_2 through reforestation; Indonesia, Congo, India, Malaysia also rank high.[18]

Even more effective would be to plant forests where none have existed in living memory, or afforestation, as in schemes for greening the Sahara.[19] Deserts would be virgin territory. One idea is to transform the seas of sand in the Middle East into woodlands: now that electricity from solar power has become so cheap, it can be used to run desalination plants on a scale large enough to truly make the desert bloom.[20] Few if any parts of the world are so blessed with a combination of bare land and sunlight and seawater as the Gulf. One early study modelled how the villas of Abu Dhabi could be turned 'carbon negative' through a circuit of solar panels powering desalination plants, the water from which could be used to irrigate land and plant trees in pleasant groves around the mansions.[21] The extended vision is a version of reparation: a region that has done so much to release CO_2 will suck it back by an extreme ecological makeover. At least one company jumped at the idea, but first applied it to a part of the US. A former CEO of Reddit, likewise a manager at PayPal and Facebook, set up Terraformation – modesty never a virtue when picking a name for a removal enterprise – and installed a solar-powered desalination plant on parched, desert-like land in Hawaii.[22] It produced about as much 'as it takes to water a golf course'; but the output was used for watering native tree species and selling carbon credits.[23]

Companies in the business of such credits have long had a taste for planting trees. The allure of these 'magic machines' is their cheapness, but they come wrapped in a panoply of added benefits. They offer shade, cool the surroundings, tie down the soil, stem floods, soothe stressed souls, provide habitats to animals and much, much more.[24] The head of Lex, 'the agenda-setting premium commentary service on global capital' hosted by the *Financial Times*, praised trees for stalling global warming *and* lifting spirits – so 'plant them, climb them, bathe with them'.[25] The reason for their ability to inspire a Trump as well as a Monbiot is this unthreatening character and universal charm. Natural climate solutions have long been framed as a win–win concept, a package of omni-solutions that would, not the least importantly, address the biodiversity crisis as much as that of climate.[26] They could also help with adaptation. Rehabilitated mangroves would bind CO_2 *and* re-erect a natural rampart against storm surges.[27] Revivifying biodiversity and recreating a liveable climate here blend into one quest. Animals at higher trophic levels may be particularly useful

‘tools’ for it, since they, apart from their own value, also control much of what goes on in the local carbon cycle. And just like everyone loves a tree, who could be against some charismatic megafauna?

The wildebeest of the Serengeti have become a standard example. As they track the lush vegetation of the savanna in great perambulations, they digest plants and discharge them as dung and thereby feed microbes, which entomb the excreted carbon below ground. But in the early twentieth century, rinderpest transmitted from livestock killed off the migrating wildebeest. Grasslands grew high and easily caught fire. The Serengeti became a source of CO_2 – until the wildebeest population was restored, the fires suppressed, the grassland chewed up, the carbon incorporated in the soil, the source turned sink again.[28] Elephants roaming through forests will disperse the seeds of overstory trees dense with carbon and tread down their understory competitors.[29] Wolves eat the moose that eat too much vegetation.[30] The idea is here to ‘animate the carbon cycle’ through trophic rewilding – or, to reintroduce keystone species that set the cycle spinning.[31] It has caught on in certain business circles, where the ownership of vast tracts of land can be combined with care for the planet and some money-making on the side. A typical specimen would be Jonathan Oppenheimer. This South African billionaire owed his fortune to the family firm Anglo-American, the world’s third largest exporter of steel-making coal, inheritor of the empire of diamond and platinum and other mines set up by Cecil Rhodes.[32] Oppenheimer ploughed some of that money into Rewild Capital – an oxymoronic company name if ever there was one – whose business idea it was to stock the largest private game reserve in South Africa, in the Kalahari Desert, with just the right amount of wild animals to sequester the most carbon in the soil.[33]

Closer to the metropolitan home, 400 individuals still owned half of the private land in Scotland, as of the early 2020s – nearly South African levels of inequality, minus the racial order. Here a class fraction of ‘green lairds’ handed over their estates to wild nature. Several touted the revenue stream from carbon credits; some eyed the reintroduction of wolves.[34] Further to the north, there was a vision for reanimating the mammoth steppe of the last ice age. If herds of bison and horses were let loose over the northernmost lands of America and Russia, they would trample the soil, keep it compact and prevent the carbon from leaking out, saving the permafrost and setting

various dynamics of removal in motion.[35] Such ‘megafaunal ecological engineering’ had an outer horizon in the art of de-extinction. At Harvard University, there was George Church, a professor of genetics and another ‘serial entrepreneur’, who worked hard on ‘enabling us to engineer cells resistant to all viruses, to grow our own liver in a pig to replace the faulty one we were born with, and to grow a brain in a petri dish’; he also had an idea for how to treat global warming.[36] If only a few dozen changes were made to the genome of the elephant, it would look more like a woolly mammoth. It would have an extra layer of fat and long, thick hair. Released into the Arctic, herds of this quasi-mammoth would preserve the permafrost, pack more organic matter into the ground and ‘possibly reverse’ global warming.[37]

Another frontier for such engineering was photosynthesis itself. The plants of old could make a hawkish remover restless. One team of scientists observed that ‘existing land plants cannot meet the ambitious requirements for CO_2 removal’ because of their ‘low photosynthetic efficiency’, so let us invent better ones: ‘There is an urgent need for genetic improvement of existing plants or construction of novel plant systems.’[38] Roots ought to be fattened and elongated. This would sink more biomass into the ground. There should be a wide and fast ‘phloem highway’ – phloem being the vascular tissue that transports carbon from leaves to roots, highway the inevitable metaphor.[39] The business world was not slow on the uptake. One California startup operating under the name Living Carbon called the approach ‘photosynthesis enhancement’, a euphemism for genetic modification. In 2022, it had arrived at the point where it could produce poplars accumulating 53 per cent more biomass than its normal forebears, or so it claimed.[40] It planted some of these super-trees on ‘underutilised timberland’ in a few places in Georgia and Ohio.[41] Carbon credits began to fly off the shelves.[42]

Another group based at the Salk Institute for Biological Studies, likewise in California, modified staples such as wheat, rice and corn. By pasting a plant compound called suberin into their genes, it turned them into ‘carbon storing machines’. Suberin ‘loves carbon’ and makes the crops hold on to it for much longer than they otherwise would.[43] The gene engineers at Salk baptised their creations ‘Ideal Plants’.[44] A third group of researchers, also located in California, received $11 million from the Chan Zuckerberg

Initiative of Facebook fame to embark on a similar project. The genes of rice and sorghum would be edited into new varieties with ‘improved photosynthesis to remove carbon from the atmosphere more efficiently’.[45] For some reason, California seemed particularly fertile soil for this kind of venture.

One did not even need plants to work this magic. Some bacteria, too, photosynthesise their way through life. Scientists had identified one such specimen in a volcanic vent off the coast of the eponymous Italian island of Vulcano. They nicknamed it Chonkus; it grew faster and thicker than most of its carbon-munching peers.[46] When cultivated in a lab, it formed a dense paste not unlike ‘green peanut butter’, an attribute that made it particularly compatible with the processes of industrial production. But Chonkus lived its life leisurely and was not optimised for removal; it did not ‘do it as well as we need to’.[47] And so it, too, was now scheduled for genetic reprogramming. In the meantime, the hunt was on for the next, as yet unidentified bacteria that would be even easier to tinker with.

Are we here still within the realm of natural climate solutions? The notion seems caught in a contradiction. If the forces of nature – photosynthesis at their core – are to be mustered for the colossal task of removing CO_2, their performance ought to be maximised. This rules out leaving nature wholly to itself. The pursuit rather invites tweaks on a spectrum running from the assisted to the manipulated to the artificial to the supernatural. If secondary forests would be good in Amazonia, they would be even better in Arabia; if megafaunal engineering could work with existing species, why not also with reinvented ones; if crops or bacteria are valued for their consumption of carbon, let us concoct the most carbon-guzzling ideal types. The engineers would still speak in the idiom of natural climate solutions – ‘what we’re trying to add to the picture of carbon capture is to utilise the natural power of plants,’ in the words of the chief scientist of Living Carbon.[48] But the category points beyond its presumed naturalness and innocence of technology: if nature is to provide the arsenal of tools for removal, the most must be made out of them. Nature must be optimised like a machine.[49] And capital has never before been wild: it has always been bent on improvement and real subsumption. At the dawn of the overshoot conjuncture, as overshoot ideology mushroomed in labs and estates, capital was thus quick to insinuate itself into the seams of things

that grow and speed them up a bit. For all the talk of harnessing nature, carbon dioxide removal here had a Daft Punk moment, as capital began to identify opportunities for making it work ‘harder, better, faster, stronger’.

Cradle of the grave

It would work harder still if plugged into actual machines. However enhanced, photosynthesis cannot instil a bottomless appetite in a plant. Trees consume carbon until they stand tall and firm and satiated; as a forest matures, the removal effect tapers off. Sooner or later, the trees will die and give back to the atmosphere what they have borrowed. But what if they were to be harvested before ageing and replaced by fresh seedlings? And why not use all that wood for some productive purpose while preventing the carbon from slipping back out? Voilà, you have invented ‘bioenergy carbon capture and storage’, or BECCS. Plant fast-growing trees, let them reach peak absorption, cut them down, ship them off to furnaces, produce electricity as from any fuel driving a generator – it could be coal, it could be gas; it can be biomass – and capture the resulting column of smoke. Stick into it a chemical element that reacts with the CO_2. Lead the captive away, pressure it and turn it from gas to liquid and force it somewhere deep underground, where it will become one with the rock. Put the process on repeat, and you have manufactured a biological pump, at the same time energetic and geological. The photosynthetic apparatus feeds carbon into trees – not once but perpetually, as one generation is culled for the next. The wood does not just stand there idly – it is utilised for the age-old purpose of burning to get energy. Best of all, the carbon exits the active cycle and is returned to the grave like a ghost put to rest.

So this is BECCS, an eyesore among the ugly acronyms of late climate politics; as we saw in *Overshoot*, the idea that first inspired the conjuncture; in that sense, the original negative emissions technology. BECCS allowed modellers and makers of policy to imagine that a temperature goal could first be missed and then hit. BECCS would recall the excess carbon to Earth. Its homeland was Sweden, essentially one giant timber plantation. At the turn of the millennium, a group of Swedish researchers took inspiration from ‘carbon capture and storage’, or CCS, a technology slapped onto

fossil-fuelled plants, most easily envisioned as a filter on the smokestack, catching and isolating the CO_2. This in itself does not create negative emissions: it just prevents the gas from slipping out into the air. But the Swedes realised that CCS could also be pasted onto biomass facilities. Given the incessant work of photosynthesis, the result would be a continuous removal loop. It would also allow companies in the sizable Swedish pulp and paper industry to sell carbon credits.[50] Researchers at an influential IAM hub in Vienna teamed up with a few Swedes and extrapolated the findings to the earth; in the excitement, they wrote up a paper for *Science* in two weeks.[51] 'Technologies that can rapidly remove greenhouse gases from the atmosphere will play an important role, particularly if unforeseen catastrophic damages are expected to significantly decrease human welfare and natural capital.'[52] And now a rabbit could be produced out of this hat: BECCS would be able to remove hundreds and hundreds of gigatonnes over the twenty-first century, 'enough to neutralise historical fossil fuel emissions' and satisfy much of the world's energy demand in the process.[53] What's not to like?

BECCS became the darling of those who created overshoot ideology. The trust in its capacities was so intense that the schemes for overshoot-and-return that achieved hegemony around Paris pivoted on this tech.[54] There was at that moment exactly one BECCS plant in operation in the world, in Illinois. When the 2020s dawned, two decades after the *Science* paper, this was still the case: the central plans for returning the planet to tolerable temperatures bargained on a technology that existed in one location, in Illinois.[55] But this was now, perhaps, about to change. Stockholm Exergi, the half-private, half-public utility of the Swedish capital, owned a power plant that burned wood material from the nation's forests and turned it into electricity plus district heating. It now had plans to stick an installation onto it that would catch, purify and liquify the CO_2, store it in cisterns, put it on boats and ship it to the North Sea for burial in deep chambers.[56] The facility was scheduled to open in 2026. Before long, the company claimed, BECCS would be sopping up twice the CO_2 released from the city's car traffic, 'directly contributing to the cooling of the atmosphere [*sic*]' – extended to the global scale, 'ultimately rebalancing the climate sustainably'.[57] The EU's innovation fund sponsored the project.[58] The company sold credits to

other companies keen to pay for the promise of future removal.[59] ‘Stockholm sucks’, read the advertisement plastered over Svante Arrhenius’s old hometown.[60]

If the race for realising BECCS was now on, Sweden had one of its fiercest competitors in Britain. In the mining districts of Yorkshire, ancient bosoms of fossil capital, a plant by the name of Drax was built to burn coal in the 1970s (not be confused with Drax the Destroyer, created around the same time). It rose to prominence as the power station emitting most CO_2 in all of Western Europe. In 2006, Drax was the target of the first climate camp, inaugurating a tactic used by the movement to considerable effect; drawing fire, it abandoned coal for biomass over the course of the 2010s.[61] On the supposition that CO_2 from its chimneys would be sucked out by new trees, this made the plant carbon neutral.[62] The next step would be to turn it negative: in early 2024, Drax announced its coming transfiguration into ‘the world’s largest carbon removals facility’.[63] The first conclusively deforested country in Europe, Britain had no forests of its own with which to nurse a BECCS plant; Drax would have to keep importing wood from North America. But Britain did have depleted oil and gas fields into which the CO_2 could be injected.[64] The negative afterlife of Drax would begin around 2030, or three decades after the *Science* article, unless beset by delays.[65] Perhaps a crawl more than a race, some diffusion of BECCS also happened in the US, where Drax aimed to establish a couple of other plants.[66] Investors in North Dakota fitted the tech onto a facility producing ethanol from corn and promptly issued the largest batch of credits for ‘durable carbon removal’ to date.[67] Inching beyond its Swedish cradle, BECCS was, possibly, about to take its first steps out into the real world.

All the powers of bio

Smart brains can squeeze more services out of biomass. Plant matter can be collected and locked into a closed space and heated up, without it catching fire. In the absence of oxygen and combustion, the matter will solidify into hard scraps of almost pure carbon, not unlike charcoal. It becomes a black, recalcitrant substance that can then be ground into smaller bits and infused

into the soil, where it will hold the element in extended detention.[68] This is ‘biochar’, produced through the process of ‘pyrolysis’, according to principles known since time immemorial – most famously, in the remotest depths of the Amazon basin. Scientists were here surprised to find rich soils in what would normally be layers poor in nutrients. Closer examination revealed that the beds were of indisputable anthropogenic origin and predated the arrival of Europeans. Indigenous communities, it turned out, had deliberately mixed charred wood, bone fragments, broken pottery and various crop residues to create what became known as ‘Amazonian dark earths’, or *terra preta*. Sprinkled into the fields, this potent blend boosted fertility and propped up agricultural practices in the region, allowing bountiful harvests where none would otherwise be possible. Of special interest in this conjuncture, it also doubled or tripled the carbon content of the soil. Crystals of C, more solid and durable than unprocessed litter, were embedded in the dark earths.[69]

When the search for negative emissions technologies took off around Paris, there ensued a frenzy for biochar. Associated with *terra preta*, it acquired an aura as something like the ayahuasca of the removal industry, a cure wise indigenous people had practised forever and left for us moderns to adopt. It would reinvigorate marginal fields. It would keep the carbon hard like pellets.[70] It attracted enormous scholarly interest: of all the studies published on removal by 2023, no less than 40 per cent focused on biochar.[71] Here the enthusiasm stretched from California to Guandong, a large share of the peer-reviewed studies issuing from Chinese institutions. Money came from the golden state and other American vaults. As we write this, anyone with a few dollars to spare can log onto puro.earth – ‘the world’s leading crediting platform for engineered carbon removal’, aspiring to be an Amazon of drawdown – and shop around among 55 biochar projects from all over the world.[72] Many signal the virtue of care for waste products. Crop residues that would otherwise languish on fields can be picked up and refined into magnets of removal. (We shall return to the particular attraction this kind of recycling has for capital.) ‘For centuries’, one firm vending its services on puro.earth tells us, ‘sugar cane waste has been burned or been left to decompose.’ But now an eagle has descended on the field: ‘American BioCarbon responsibly repurposes this material to remove carbon from the atmosphere.’[73] One can picture the heroic

executive of American BioCarbon, star-spangled banner slowly waving in the wind behind him, emerging over the horizon with his brand-new sugar cane waste collector. Once the stalks have been reaped, all kinds of other materials could be fed into the pyrolyser – leftovers from BECCS, for instance.[74] The future of biomass residue is for the bold.

We could even clean up natural forests while at it. One startup offhandedly noted that these are 'typically littered with dead trees', evidently a wasteful cycle of decay; better to glean the fallen carbon and put it out of reach of rot.[75] More biochar could be brewed, but the trunks could also be directly 'buried in trenches or stowed away in above-ground shelters'.[76] One more route of removal: dump trees in mass graves, be it in 'trenches' or in any kind of abandoned hangar. Power plants and pyrolysis would here be skipped and the necromass headed straight for sepulture. Two researchers with a penchant for marketing came up with the name 'The Wood Vault' for this method.[77] In 2022, a startup called Kodama – based, yes, in California – received millions of dollars from Bill Gates and other patrons to help put it into practice. It claimed to be developing 'automated ways of thinning out overcrowded forests': picture a robot stripping off the smaller limbs from Californian trees and loading them onto trucks and waving goodbye as they depart for a 'burial mound in the Nevada desert that's seven yards high'.[78] It would be a wonder of postmodernist epoch-mashing: the Bronze Age and gleaning and artificial intelligence all rolled into one. There was, inevitably, a new acronym on the block: BiCRS, for 'biomass with carbon removal and storage'. The removal cognoscenti pronounced it as 'bikers'. In words that resembled those of counterinsurgency, some instead spoke of 'wood carbon containment'.[79]

Yet another route is to convert plant material into something called bio-oil. Here the idea is to take spilled straw and stalks from fields, cook them up into a black sticky liquid and then pump that down depleted oil wells. A San Francisco startup called Charm Industrial started doing this.[80] Founded in 2018 by four engineers looking to make a difference, the company offered a special charm: 'We're putting oil back into the same formations that held it for hundreds of millions of years.'[81] Investors happily doled out funds. Charm rose in the ranks of removal startups, receiving several hundreds of millions of dollars in 2023 alone from the likes of Alphabet (i.e. Google), Meta (i.e. Facebook) and JPMorgan.[82] By that year, it had

funnelled some 6,200 tonnes of CO_2 underground – a piddling amount, but more than any other removal startup had managed up to that point.[83] One of the four founders did not mince words on where they wanted to go next: 'I think we have a way to make this potentially the largest negative carbon company that's ever existed.'[84] Or, as the CEO liked to exclaim: 'Gigatons or bust!'[85]

But then a company called Vaulted Deep came up with an even more riveting idea: why go through the effort of turning waste into bio-oil, when you could just pump it down directly? Their 'advanced slurry sequestration technology' allowed them to 'take minimally processed, abundant, organic wastes' and flush them down into abandoned oil wells. This, it claimed, would yield '10,000+ year permanent storage'.[86] It scavenged for the same agricultural scraps as Charm, but its biggest potential came from another source. In Los Angeles, it started collecting the city's sewage to work its magic on. The treated excrement of that city's inhabitants would ordinarily be sent far and wide to be spread out on farmland as fertiliser, 'releasing CO_2 both during the transport and as it decays'. Now Vaulted Deep would lock it up as a permanent sink. The US population collectively defecated one billion tonnes of this stuff every year. In some utopian future all of it could be captured and sunk in the ground. There appeared to be, one journalist observed, 'growing excitement for the dumbest, most primitive solutions companies can come up with'. But investors indeed were thrilled. One of them was Frontier.[87] This was an organisation providing 'advanced market commitment', a source of money to be rained on anyone who came up with an alluring removal idea, modelled on vaccine development, pooled together by the likes of Alphabet, Meta, Shopify, McKinsey.[88] It gave Vaulted Deep its largest cheque yet: 'At the end of the day, we are really excited about getting to gigaton scale carbon removal, and it doesn't have to be the sexiest technology.'[89] Take a shit, sink some carbon.

Lost at sea

Move on to the ocean sink and whole new vistas open up. It covers two thirds of the globe. It has no people in it. Already prior to the administration

of stimulants, it gulps up about a quarter of the emitted CO_2: there is a lot to be said for the ocean as a 'solution space'.[90] Since Paris, the buzz has centred on the notion of 'blue carbon', meaning carbon stored in water, first along the shorelines, in mangroves and seagrass meadows, then further out on the endless voyages of the engineering imagination.[91] One could, for example, set sail with seaweed. Rather than using it as material for shampoo or sushi, one could cultivate the crop and send it out to the open sea and sink it into the abyss.[92] This would give a boost to the biological pump, proponents have argued, further extending the category of natural climate solutions.[93] If the stuff reaches deep waters devoid of oxygen and sunlight, it will, at least for some time, be sheltered from decomposition.

There was a startup before there was a science of this practice. In 2017, Marty Odlin, a go-getter with a fleet of five fishing boats in Maine, set up Running Tide to, as the slogan went, push carbon 'from the forest floor to the ocean floor'.[94] Build buoys of wood residues. Seed them with select species of seaweed. Set them adrift – Running Tide worked from a base in Iceland – and watch the fleet of buoys build up over the months, the balls of algae bobbing on the surface and growing and absorbing CO_2, until they become so heavy as to sink to the bottom, where the pressure of the water column will keep them in place for centuries or maybe millennia.[95] Running Tide attracted a few million dollars from familiar names – Microsoft, the Chan Zuckerberg Initiative, Shopify – and Odlin counted on more.[96] 'If we're able to unlock growth in the open ocean, which we think is feasible, it has the potential to scale up to be quite big.'[97] He fancied his new business a 'global ocean health company'.[98] His competitor Pull to Refresh went for a fleet of unmanned, solar-powered vessels that could be sent far out at sea with giant vases of bladder kelp to be emptied into the depths. 'With a small amount of open ocean, we can get back to preindustrial levels,' claimed founder Arin Crumley, a Silicon Valley bro who had previously worked on electric skateboards.[99]

One could turn the map around in any direction: one might as well bring the seaweed onshore. A versatile crop, it can be used as a feedstock for biochar or BECCS; there were startups fishing in these lanes too.[100] Or one could forget about seaweed and go for the biomass lying around on land. The ocean may be the ideal wood vault. An entity always riding the waves from the West, the state of Israel sported a raft of startups in the removal

business; one called itself Rewind and ran, unoriginally, with the motto 'Rewind the clock on climate change'.[101] An Israeli man sold a software company to Google in 2019. He took his money and presented his idea to the Israeli Innovation Authority, among other backers from his state. The elevator pitch was to jettison waste carbon in the Black Sea. A strangely stratified body of water, almost no oxygen finds its way into its bottom, leaving it free of ravaging microbes; as ships have sunk over the centuries, they have left behind a museum of hulls and masts and rudders looking just as when they were built. Even ropes are intact. Having experimented with drowning pine in the Sea of Galilee, this company concluded that it had indeed struck on a unique proprietary technology for rewinding the clock on climate change and drew up plans for collecting dead plants piling up around the Black Sea and putting them in sacks and putting the sacks in cages and driving them out on barges, 'purposefully adding to the wreckage'.[102]

Another Israeli startup hit on another bright idea: kill algal blooms. BlueGreen Water Technologies aimed at the biomass overpopulating lakes and rivers around the world. Warmer waters overflowing with nitrogen make cyanobacteria run riot. This Israeli company was founded in 2014 to clean up such pollution, but then it realised it had struck upon a solution to a bigger problem. By injecting hydrogen peroxide – a chemical compound used in bleaching – into water bodies, it induced 'cyanobacterial suicide'; the water would clear in a day or two, the surface turn blue again, the dead algae taking (some of) their carbon into the sediments. 'Today, we are a company that removes fantastic amounts of carbon, and by the way, cleans up lakes,' the CEO boasted in 2023.[103] He trademarked the name 'Net Blue' for the method and suggested it could become 'the most desired form of carbon credits in the world'.[104]

But inverting the method might be desirable too. 'In the past recent years, carbon dioxide (CO_2) emissions have been continuously rising, and the same trend is expected for the future,' began one article, which, therefore, proposed to intervene in the genome of microalgae and give them a bit of photosynthesis enhancement. Here the aim would be controlled mega-blooms in bioreactors and ponds and other bodies of water – let a hundred varieties bloom.[105] Brilliant Planet had its own brilliant idea for how best to do it. Kickstarting the process in a laboratory, it would transfer the blobs of

algae to ponds in the Moroccan desert and generate a concentrated ‘slurry’ of biomass to be sent up a tower. From this tower, the company would spray the mixture into the hot and dry desert air and watch it float back to the ground. The powdery particles would then be collected and dispatched to landfills for permanent storage – a tortuous route it might seem, but one that made Brilliant Planet the highest-ranking ocean removal company in 2023.[106]

Do not close this catalogue yet! Keep scrolling! There is plenty more to come! Ocean-Based Climate Solutions Inc. wanted to do ‘artificial upwelling’ – ‘a technology that converts CO_2 into ocean fish food’. Deep oceans contain nutrient-rich waters, but they lack the sunlight marine organisms need to grow. At the surface, the reverse holds: lots of sun, not enough nutrients. From a certain perspective, the performance of the ocean is thus suboptimal; but that could be changed. One could deploy a mechanical device – think of a giant blender – and churn the deep fertile waters up to meet the light. This would open a banquet to phytoplankton and other algae, which in turn would invite other critters along the food chain, until the generalised feast ends in death and decay and a slow descent into the vault.[107] In what might have been the first proposal in this genre, none other than James Lovelock, father of the Gaia hypothesis, suggested pipes up to 200 metres long and 10 in diameter for shooting water up to the surface.[108] One could perhaps think of them as fabricated mega-straws for the algae. Or one could do ‘downwelling’: stir up the top layers and propel their CO_2 in the direction of the nutrients below for quicker photosynthesis.[109] Or one could dispense with machines and opt for a natural solution to jump-start the pump: whales.

Whales are the original upwellers. They trawl the deep seas, feed on krill, fish, squid and other creatures rich in nutrients and then rise to the surface to breathe and rest and defecate. Through their excreta, they pepper the upper layers with iron and nitrogen for others to ingest; and so, it follows, protection and restoration of whales – another act of trophic rewilding – would give the biological pump a stimulus, provided the whales can be made to save their faeces for the right ocean patches. Or that was the idea. Researchers were looking into it in the early 2020s.[110] But money did not sit idly waiting for the results. An enterprise calling itself The Whale Carbon Plus Project gathered funding for remote sensing of the movement

of whales and attendant production of carbon credits.[111] The IMF declared that ‘when it comes to saving the planet, one whale is worth thousands of trees’ and considered, along with other like-minded institutions, ways of bringing whale poo to the marketplace.[112] And so, in the early 2020s, as heatwave after heatwave scorched the planet and ocean temperatures rose beyond anything ever seen, to say nothing of the capital flowing into the extraction of fossil fuels, some members of the dominant class dedicated their time, without any apparent irony, to initiatives casting whales as ‘climate warriors, absorbing huge amounts of carbon dioxide in their gargantuan bodies while pooping in such great quantities as to stimulate the growth of other CO_2-consuming organisms in the ocean’.[113] Help reverse climate change: buy whale poo credits. Somehow, it seemed to make sense.

John Martin the Baptist

The most illustrious aquatic technique, however, featured a human hand as the dispenser of nutrients. It arose out of a rather old discovery. As early as the 1930s, scientists found that phytoplankton, the microscopic plants that live in the uppermost layers of the sea, are responsible for half of all photosynthesis on the planet and make up a cornerstone for marine ecosystems.[114] Some ocean patches appear particularly rich in them, while others do not, for reasons that long remained a mystery. The barren parts ought to be as rich as any. It was speculated that the difference had to do with a deficiency in trace minerals, in particular iron.[115] This hypothesis proved difficult to verify, because water was easily contaminated with metal leaking from the measuring equipment. But in the late 1980s, an enthusiastic oceanographer called John Martin came along.[116] Working out of a laboratory in California, he collected samples from various parts of the ocean, brought them back in bottles, rigorously cleaned his equipment and added iron. Not only was the iron hypothesis borne out, it might, Martin figured, have far-reaching implications for the climate. High levels of phytoplankton in certain regions – the Southern Ocean, above all – seemed to correspond with the onset of ice ages. Martin knew that there was more dust in the air during such ages, and dust from arid lands contains iron, and so he inferred that the initial dip in temperatures sent iron-rich dust blowing

into the oceans, where it triggered a feeding binge among the long-starved phytoplankton. This ‘turned on’ the biological pump – another feedback mechanism of the glacial cycle, further suppressing CO_2 concentrations and temperatures.[117] Now what might the cue be here?

Martin’s main intellectual contribution was to solve a long-standing mystery in oceanography, but he could not help also extracting a message for hotter times. Currently, he observed, ‘southern-ocean phytoplankton are not receiving essential iron, the biological pump is turned off, and relatively little CO_2 is being removed from the atmosphere.’[118] But the pump could be artificially turned on. Very little iron seemed to be needed – ‘a few hundred thousand tons’, said Martin’s back-of-the-envelope calculation.[119] The idea was simply to spread iron filings like fertiliser on the sea and thereby provoke a growth spurt of phytoplankton. Boats would be outfitted with hoses. ‘Oceanic iron fertilization’ might ‘turn out to be the most feasible method of stimulating the active removal of greenhouse gas CO_2 from the atmosphere, if the need arises.’[120] The *Washington Post* got the message and ran a front-page story headlined ‘Ironing out “Greenhouse Effect”’. It featured the extemporaneous words with which Martin’s name would henceforth be associated: ‘You give me half a tanker full of iron, I’ll give you another Ice Age.’[121] The *Post* article sparked an uproar. Martin became a celebrity scientist, nicknamed ‘Iron Man’ in the American press and ‘besieged by calls’, some supportive, others less so.[122] In hindsight, he appears as one of many John the Baptists of removal, announcing the coming of a saviour technology to wash away our sins.

Stone dead

Carbon is drawn down by things that live on Earth, and by things that do not live: storm, stone, shell, sea. The largest natural sequestration happens over time through the latter class of objects. Some of the CO_2 the air holds dissolves into rainwater, which then acidifies, if only ever so slightly. As the faintly acid rain falls on rocky ground, some stone – particularly silicate – is in turn dissolved, or, with the scientific term for this process, weathered. As the fragments of stone react with the carbonic acid, they form carbonates,

micro-minerals with a C in them; and as these compounds run along with the water, they eventually make their way to the sea. Creatures use them to build shells. These are the animate carriers of the cycle, which, however, returns to the inanimate base when they die and their shells and skeletons are integrated into the seabed and at last turn into limestone: an aeon after it fell as a raindrop, the carbon has calcified. This is the kind of process beloved by a Hutton or Lyell. Weathering really *non facit saltum*; it is ultra-gradual. It forms the most slowly revolving wheel in the carbon cycle, but it transports such astronomical amounts as to make the difference between Earth and Venus.[123] Without it, our atmosphere would have overflowed with CO_2 long before any humans could breathe it in – here is, in the words of Wake Smith, 'the drain in our proverbial bathtub', the process by which nature ejects carbons from air and locks it up in stone. But 'it takes for-flipping-ever!'[124] Around the turn of the millennium, weathering removed around one gigatonne of CO_2 every year, compared to the nearly forty pumped up by the capitalist world-economy; hence this drain, from a human standpoint, was clogged.[125] Might its pipe be widened?

Enhanced weathering brings accelerationism to the most unhurried cycle: cover the ground in silicates. Quarry the stone, grind it to powder, spread the fine particles over land as miniscule decoys for carbon. The element will have more of the right rock to react with when it rains to the ground. One exercise in idealised modelling from 2016 suggested that enhanced weathering could be so mighty a force as to cut the concentration of CO_2 from a peak of 540 ppm back to the preferred 350 during this century.[126] The technology was conceived in the same moment as iron fertilisation, in 1990. It was pitched in a short piece in *Nature* by the Swiss physicist Walter Seifritz.[127] It was then picked up and further developed by the German physicist Klaus Lackner, who also happened to become the father of DAC; another prophet of removal, perhaps its highest priest. His early career might be read as a cautionary tale.

A man of big ideas, relocating from the Bonn Republic to the US in the early 1980s, Klaus Lackner first gained notoriety for his work at Los Alamos National Laboratory, renowned cradle of the atomic bomb. Bemoaning the timidity of his fellow scientists, no longer prone to thinking on the scale of the Manhattan or Apollo projects, he came up with a proposition for something exceedingly ground-breaking: machines capable

of replicating themselves and solving the world's most pressing problems in the process.[128] He imagined them as robots no larger than suitcases. He would position them on a yard of desert land. Observing a strict division of labour, some would scrape dirt from the desert floor, others extract useful metals from the dirt, yet others shape them into machine parts and assemble new replicas of all these lines of automata. Some would repair them when they broke. From a Greek word for 'to grow', Lackner gave his robots the name *auxons*. Doubling in number every six months, fanning out across the American continent, the population of auxons would be programmed to execute three more tasks: build solar panels, thereby supplying unlimited energy to themselves and all humanity; construct water-desalination units; and, last but not least, convert airborne CO_2 into 'a layer of "marble" approximately 50 cm thick'.[129] And all this with no inputs other than sunlight and air and raw, common dirt. In 1995, *Discovery Magazine* listed it as 'one of seven ideas that can change the world'.[130] No auxon has since been sighted. Representing a recurring dream of bourgeois civilisation – fully-automated labouring armies, capable of moving and begetting themselves, with no will or deviation – the scheme might have run up against the laws of thermodynamics.[131] Lackner seems to have quietly dropped it.

He did stay, though, with the idea of turning CO_2 into 'marble'. In the year of the auxon paper, Lackner and his colleagues at Los Alamos laid out the ABC of enhanced weathering.[132] Mining rock and pulverising it and diffusing the dust would create more surface area with which to trap carbon. A 'safe and permanent method of CO_2 disposal', it would require a lot of that rock, but the 'necessary raw materials are available in vast quantities, far exceeding the known fossil fuel reserves'.[133] Measured by the quantum of companies that pursued some version of this idea by the early 2020s, here, at least, was one way in which Lackner et al. really did change the world. Their success could be read off the ledger of Frontier. A fair bit of the $1 billion Frontier controlled went to companies with visions for enhanced weathering.[134] One was called Lithos, Greek for 'stone'. It started grinding up basalt, the most common volcanic rock, and spattering it over farmland. Three tonnes of basalt would, Lithos claimed, yield one ton of

CO_2 ‘permanently deposited at the ocean floor’.[135] Lithos was a favourite of Frontier.[136]

But it was not, of course, without competitors. Vesta selected a special rock, the distinctly green olivine, to be spread directly onto beaches, whence it would gently wash carbon into the waves.[137] Crew Carbon blended ‘abundant, globally available crushed rocks’ into sewage water to bind the free-floating CO_2.[138] Arca – motto: ‘Rocking CO_2 for a livable planet’ – collaborated with companies mining critical minerals to make something useful out of the mountains of rock waste they produced anyway.[139] Blue Planet Systems wanted to assemble such waste rock and pluck CO_2 and fuse the two into synthetic limestone, which could become the building block of concrete. Let all cement production adopt the Blue Planet Systems and the entire built environment would turn into a giant carbon cemetery.[140] Self-styled climate restorer Fiekowsky avidly backed this particular idea, calling it ‘a trillion-dollar market hiding in plain sight’.[141] Replacing the 55 billion tonnes of rock currently mined for concrete every year with synthetically produced limestone would, he calculated, permanently remove all of 25 gigatonnes of CO_2 per year – more than half the emitted amount.[142] This would be a drainpipe very much widened indeed.

But the most commonly envisioned route for enhanced weathering passed through the soil, in the hot and humid tropics.[143] Under the motto ‘Carbon removal as nature intended’, one startup – InPlanet – had chosen Brazil as its theatre of operation.[144] So did competitor Terradot, which sold its goods to Google.[145] Like biochar, the rock dust was expected to improve fertility and increase agricultural yields: another win–win solution.[146] It could also be applied to golf courses. ‘Global warming poses a significant threat to society, and prompt action is needed,’ began one article that outlined how silicate minerals could be splashed over the driving ranges of the contiguous United States of America; this would uphold ‘the cultural management goals’ of said establishments – allowing golfers to keep playing golf, that is – while sequestering carbon.[147] Heavy-duty trucks would transport crushed basalt to the putting greens.[148] But one could also hurry on the process from the other end: grow a monstrous amount of mussels and oysters. These are the foragers of carbonates who mineralise

and meld them into their bodies. Their shells remain hard long after the occupants have passed on and so more of them farmed and dined up would equal more removal: an orgy of seafood to force-feed the earth with CO_2.[149] The two methods could probably be combined at a profit. First play golf on turfgrass coated in silicates and then, after the round is over, eat the oysters that receive the carbonates: truly a closed loop.

No such pleasures would come from a category of technologies called Direct Ocean Capture, or DOC. Here the idea is to empty the stomach of ocean patches so they can absorb more CO_2. If the gas is taken out, more will go in. The ocean may be regarded as 'the ideal carbon removal engine' – the grandest cog in the time machine – given how saturated it already is.[150] A company called Captura was ahead of the rest: it wanted to build floating removal facilities to suck in water from the surface, strip out the CO_2, pipe away the concentrated gas for disposal and then release the decarbonised water back into the ocean, like cleaning an aquarium. Voided of CO_2, the returning water would eagerly swallow more of it from the air, as the two sinks moved towards a new equilibrium, and so on.[151] Frontier and the US Department of Energy took a fancy to this idea.[152] So did the omnipresent Elon Musk, who launched an 'XPrize' removal competition, his own mechanism for dangling carrots in front of the inventor pack; we shall return to him and his prize below. Captura was one of the twenty finalists, and received some additional pocket money on the go.[153]

The absorption capacity of the oceans could be similarly expanded by pouring in the right chemical substances: turning the oceans more alkaline, less acidic, so that greater quantities of CO_2 would be licked up by the waves. It was a researcher at Exxon who first mooted the idea of 'ocean alkalinity enhancement'.[154] Buckets of soda ash or lime dumped into the seas would make them thirstier. Like a child who has had too much salt hurries to drink, an alkalinised ocean would imbibe more CO_2; and, if alkalinisation is sufficiently and continuously beefed up, it would beat back the harms from acidification. Every added bucketful of powder would speed up the formation of carbonates for final delivery to the bed.[155] By the early 2020s, this Exxon researcher's dream seemed close to coming true: a plethora of startups and research initiatives were busy developing their own specialities.[156] A group of scientists in Massachusetts explored the effects

of sodium hydroxide as their powder of choice. They worked under the name LOC-NESS, for ‘Locking away Ocean Carbon in the Northeast Shelf and Slope’, the irony of naming a speculative removal project after a monster of unproved existence apparently lost on this team, parapraxes galore.[157] Less sexy CREW worked with limestone and dumped it in sewage treatment plants, from where it would make its way out to sea.[158] CarbonRun planned to release the same material into rivers and streams.[159] Ebb Carbon wished to batten on desalination plants. It would intercept the treated seawater, subject it to some electrochemical splintering and take out the acid stuff and flush the rest back to the sea. (This would be ‘electrochemical ocean alkalinity enhancement’, the linguistic spiral of accumulation one step ahead of any real thing.)[160] Equatic wanted to do the same but also produce green hydrogen in the process; it was already building its first commercial plants in Singapore and Quebec.[161] But it was Planetary Tech that combined the approaches in the most comprehensive manner. It was learning to kill ‘four birds with one stone’: purifying mining waste into a safe alkaline material, throwing it into the sea – removing carbon, countering acidification – producing green hydrogen and yielding a number of valuable materials for battery manufacturing in the process.[162] Perhaps that counts as five stones. There can never be too many chucked into the sea.

The quest for a chemical liquor

Last but certainly not least, there is the option of bypassing nature altogether. This solution does not bother with perking up some pre-existing process of sequestration. It assigns the work straight to a machine. There is no mediation between atmosphere and final resting place other than an advanced contraption: the logic of Direct Air Capture, or DAC. One popular science account, *Scrubbing the Sky: Inside the Race to Cool the Planet* by Paul McKendrick, traces this technology to as far back as the early seventeenth century.[163] A Dutch alchemist and serial inventor by the name of Cornelis Drebbel had taken up position in the English court. He entertained King James I with several amazing contrivances: a perpetual motion machine, a self-regulating oven, a magic lantern, a device producing

thunder and lightning.[164] But his most jaw-dropping feat was the first recorded submarine in history. In 1621, Drebbel launched a wooden boat on the Thames fully covered with leather. Under the skin sat twelve rowers, each holding a pair of oars sticking out through tightly sealed holes. The boat was designed and weighted in such a way that when they paddled, it moved downwards, below the surface, where it reportedly stayed for three hours before appearing again, to a great roar and applause.[165] The audience was awe-struck: how could the oarsmen survive in that confined space for so long? There seems to have been an intuitive understanding of the risk for poisoning from elevated levels of carbon dioxide.[166]

When humans inhale, the oxygen passes into the blood; when they exhale, what comes out is carbon dioxide; if the air is closed off from the atmosphere, the O supplies will be depleted and the CO_2 concentrations rise so high as to cause headaches and lethargy and eventually metabolic collapse – a law familiar to anyone who has spent time in a packed room without ventilation. Some reconstructions suggest that the rowers in Drebbel's submarine ought to have suffered from excess CO_2 after about half an hour.[167] So what trick did he play? McKendrick infers that he must have built a proto-DAC machine for scrubbing the air.[168] This, however, appears unlikely. The modern literature on Drebbel contains three hypotheses: his boat never actually went below the surface, merely producing the illusion of doing so; it was outfitted with a snorkel system; or, he refilled it with oxygen by heating saltpetre.[169] As for his contemporaries, they favoured a different explanation: magic. Their accounts suggest 'that the alchemist Drebbel could completely refresh the air within his boat by dropping a few drops of an unknown magical mystery liquid on the floor'.[170] The most authoritative account was penned by Robert Boyle, founder of chemistry as a scientific discipline, who was fully aware that 'a certain Quintessence' or 'spirituous part' of the air is what makes it breathable. When this element is spent, only a 'carcass' – read: excess CO_2 – remains, 'unable to cherish the vitall flame residing in the heart'. Boyle concluded that Drebbel's secret proprietary technology must have been some kind of 'Chymicall liquor'. When

> from time to time he perceive'd, that the finer and purer part of the Air was consum'd, or over clogg'd by the respiration, and steams of those that went in his ship, he would, by unstopping a

> vessel full of this liquor, speedily restore to the troubled Air such a proportion of Vitall parts, as would make it againe, for a good while, fit for Respiration.[171]

'Four centuries later, and in need of scrubbing a vastly larger volume of carbon dioxide, we may come to rely on the same concept,' writes McKendrick.[172]

Whatever sleight of hand Drebbel performed on the Thames, and we will probably never know for sure, from the 1930s onwards, oil-fuelled submarines in the arsenal of the US navy were in fact equipped with scrubbers to remove CO_2.[173] So were, a couple of decades later, spacecraft.[174] The basic technology was proven and operational when, fresh from the auxon paper, Klaus Lackner put his mind to removal from the atmosphere as a whole. In 1999, he and his colleagues from Los Alamos published the first proofs for the viability of DAC.[175] 'Photosynthesising plants already collect carbon dioxide from the air'; the trick is to find a chemical liquor to emulate their operations.[176] For his choice, Lackner followed the lead of his daughter Claire, who applied it to an experiment for an eighth-grade science fair. She used an aquarium pump to bubble air through a tube of water mixed up with sodium hydroxide (later also the choice of LOC-NESS). Because this compound is a base, it would bind with the acid CO_2, the air emerging from the other side stripped of most of the gas. 'Simply bubbling air through a wash bottle removes the bulk of the CO_2,' Klaus et al. observed, citing Claire Lackner (who went on to earn a PhD in astrophysics and work for Netflix).[177] Eight years down the road, the father, now at the Earth Institute of Columbia University, put on display the first working DAC contraption. It was 2007, a year of intense attention to the climate problem in Western politics (eclipsed only in 2018–19). In its communiqué, Columbia hailed Lackner's invention as a 'critical solution' destined to 'help the world reduce dangerous amounts of CO_2 in the air'.[178]

The basic principles are straightforward enough. Air needs to pass through an object that selectively grabs the CO_2 molecules contained in it. In an American submarine or spaceship, this would be referred to as a 'molecular sieve': a device in which CO_2 and CO_2 alone gets stuck, while the rest of the air transits unaffected; it can then be breathed again by the cabin crew, the concentrated hazard tossed out.[179] In this sense, the military

apparatus of the US empire spoke of ‘carbon dioxide removal’ long before climate became an issue.[180] DAC updates the principles for the overshoot conjuncture. At the core of it is the ‘sorbent’, the material that snatches the molecules of CO_2 with precision and lets all other air components waft away. It can operate through ‘absorption’, the particles entering the body of the substance, or ‘adsorption’, the particles sticking to its surface – a distinction similar to that between eating an animal and wearing it. When the sorbent is filled up with CO_2, it is taken away and divested of this content. It will then be ready for a new round. The pure CO_2 is safely disposed of somewhere.[181]

DAC makes no pretension to fiddle with photosynthesis from the inside, only to copy certain aspects of it. DAC works not by intrusion but mimesis. DAC, however, cannot escape nature as such. Like any other artifice, it must rather submit to nature – nature being ‘those material structures and processes that are independent of human activity (in the sense that they are not a humanly created product), and whose forces and causal powers are the necessary conditions of every human practice, and determine the possible forms it can take’.[182] Most unforgivingly, the laws of thermodynamics impose constraints on Direct Air Capture. In a lump of coal or barrel of oil, potential energy is densely stored. Light a match under it and the energy is released as in a blowout. On the other side of combustion, the CO_2 molecules are thinly dispersed in the air, like soot flakes in a gale: catching them demands a much greater effort.[183] Even at 400 or 600 ppm, the concentration is not anywhere near what it would have been in Drebbel’s submarine after half an hour. However large the excesses, CO_2 stays diluted outdoors. From a thermodynamic perspective, DAC will always be like finding a needle in a haystack – which is not to say that it is physically impossible. Lackner and his disciples have indeed disproved the pessimists who deemed their quest futile by definition.[184] What they have not done, however – any more than a perpetual motion machine or an auxon – is to break through the barriers of thermodynamics: energy expended on removing a substance will, as a matter of law, be inversely proportional to its concentration. Every conceivable type of DAC machine must devour energy.[185]

It must do so at the points of entry as well as exit. First, masses of air – and small amounts won't do: these have to be haystacks huge enough to contain the rare needle – have to be impelled towards and through the sorbent by means of a fan or similar mechanism. Second, once the sorbent is saturated, it has to be heated up for it to let go of the catch.[186] More is demanded of this filter than in a BECCS or a CCS plant, where the flue yields a comparatively concentrated stream of the gas.[187] The air to be sieved here does not appear as smoke from a fireplace, but as *any* air, or 'ambient air', an average segment of atmosphere. This has compelled DAC developers to search for a medium that can bend energy consumption downwards: they want it to be porous, spongy, discriminating, recyclable, efficient in pulling out CO_2 and quick to give it up. A library of materials has been assembled – zeolite, graphene, silica, alumina, even carbon itself – in the search for the perfect sorbent.[188] A tree of startups has branched out from the stem of Lackner's first demonstration, each with its own patented idea for how to best overcome the inherent limitations. Three were dominant for long.

Closest to Lackner's home turf was Global Thermostat, briefly encountered above as a standard-bearer for the reversibility of climate change. Two colleagues at Columbia sired this company. Peter Eisenberger had already toyed with the idea of mimicking photosynthesis in the 1980s, when he worked as a high-ranking researcher at Exxon. Graciela Chichilnisky spent much of the 1990s devising the carbon markets of the Kyoto Protocol, for whose existence she would often take credit. When he told her of Lackner's prototype, she was fired up by the promise of profits; during the 2010s, they oversaw the design of the company's signal device. High-powered fans drove air through a structure similar to a honeycomb. Each cell, rotating at regular intervals, was 'full of proprietary chemicals', some unrevealed solid sorbent doing adsorption.[189] The heat required to pry away the CO_2 was reduced to just below 100°C. Chichilnisky was the CEO. She did not aim low. 'I will complete the job of reversing climate change, turn Global Thermostat into a $1 billion company, and revolutionize quantum theory using topology for the benefit of understanding what is time and who we really are,' she declared in an interview in 2020. 'I am starting a movement to bring the most amount of good to the most people. It all begins with Global Thermostat and carbon capture as my team and I

work to reverse catastrophic climate change.' As a matter of fact, 'I am very close to reversing climate change now.'[190]

Less than half a year later, Global Thermostat was a company in open crisis. While its one prototype had been exhibited at Stanford, no actual DAC plant had seen the light of day. When devices were ferried to the construction site for the first facility, they self-ignited inside their boxes. The contractor charged with building it sued Global Thermostat for unpaid bills and shut the project down. Nothing much came of anything. In a toe-curling piece, *Bloomberg* noted that this company was 'America's best hope to pull CO_2 directly from the air', but the 'staff generally totals fewer than a dozen people, and everyone at its headquarters sits together in one large room, with daily dysfunction on open display'. The CEO was at the centre of the turbulence. 'No one could deal with her lack of ability to separate the personal from the professional,' one former senior executive told *Bloomberg*, on condition of anonymity for fear of reprisals. Employees complained of being treated like Chichilnisky's personal assistants. They would be asked to grade her students' essays or fill out paperwork for her medical appointments – 'I spent 10% of the time on my stated job, 40% of my time on Columbia, and 50% managing Graciela,' testified one.[191]

She had to leave: Global Thermostat underwent a shakeup, brought in a new CEO and had another go. In early 2023, at long last, it inaugurated an actual facility, in Colorado. 'When the story of our victory in the climate crisis is written, today will be a defining moment,' proclaimed Nancy Pelosi, former speaker of the House of Representatives, at the ceremony.[192] But there was one glitch in the machine. The captured CO_2 was not stored or taken anywhere offsite. It was just vented straight back into the air, for reasons we shall return to. No carbon was sequestered in any manner at all, that is; but the facility required plenty of electricity from the Colorado grid, which, incidentally, ran primarily on coal.[193] The sum of the establishment was thus one more addition of CO_2 to the atmosphere. Global Thermostat was back in business after Chichilnisky, again feeding its audiences with reports of various breakthroughs, until in 2024 it was bought up by Zero Carbon Systems, a new entrant on the DAC scene. But by then, it had long ceded its position as frontrunner to a competitor in Europe.[194]

In early February 2020, while an as yet unnamed virus gathered force not far away, the two of us paid a visit to the Swiss village of Hinwil, a short

train ride from the ultra-affluent neighbourhoods of Zürich. There we could see them with our own eyes: actual DAC machines capturing CO_2. With a distant view of the melting glaciers of the Alps, a startup called Climeworks had planted them on the roof of a waste incinerator, tapping into the surplus heat from the burning of Zürich's garbage. The machines looked somewhat like oversized clothes dryers, rattling and whirring while drawing in air. Behind them, thick balloons straining at their leashes held pure, concentrated CO_2. This was the first commercial DAC plant in the world.[195] Because enormous hopes were invested in it, as the key unlocking a liveable future on Earth, and because Zürich is easily reached from any Western metropole, everyone from *Financial Times* to Greta Thunberg made the pilgrimage to Hinwil. 'This company is trying to save the planet, one carbon dioxide molecule at a time,' the former reported.[196] When we visited its headquarters in the city, they buzzed with febrile activity. Renovations were ongoing, office spaces expanding, a long list of new hires underway, hitherto artisanal manufacturing subjected to standardisation: a tiny startup undergoing exponential growth. Men in suits with deep pockets were beginning to throw investments at it by the millions.

What these investors were buying was an idea. At this point, any CO_2 captured at Hinwil was funnelled into a nearby greenhouse to boost cucumber growth or sold to Coca-Cola to be bottled up as fizz.[197] Where did CO_2 swallowed as cucumber or Coca-Cola end up? Back in the ambient air, of course, as soon as the consumer breathed out or burped. We shall revisit the reasons for selling out the carbon in this way. Climeworks itself, in other words, did not release CO_2 back into the air; but its customers did. Yet the company advertised a lofty plan: to capture 1 per cent of all human emissions by the year 2025, or some 400 million tonnes.[198] Few other outfits dared to dream that big, let alone build a business model around it. While doing their PhDs at the prestigious university ETH Zürich, the founders of Climeworks had experimented with submarine scrubbers and Lackner concepts, picked their own chemical liquor – an undisclosed alkaline sorbent – and reduced the heat demand to around 100°C, something that could be sourced from rubbish on fire; then, in 2017, they put up the solution on the roof of that burning trash for all the world to see.[199]

In the same year, they also took what many claimed was the real quantum leap. Climeworks opened a facility in Iceland that transformed CO_2 into stone. Called ‘Arctic Fox’, it was puny, capturing only fifty tonnes per year; but in 2021, big brother ‘Orca’ came online with a theoretical capacity to take out 4,000 tonnes, nearly two orders of magnitude more.[200] Three years later, the time had come to add another sibling to the family: ‘Mammoth’ increased capacity – supposedly – to 40,000 tonnes.[201] Here the gas would not be passed on to any customer. It would be piped down into the underground where, just as in enhanced weathering, it would become stone dead forever, or ‘mineralised’. The whole process was powered by a nearby geothermal plant. With these flagship facilities, in Switzerland and Iceland, Climeworks demonstrated that carbon can in fact be directly captured from the air and either reused or removed to the nether regions. But as 2025 loomed, it was lightyears away from capturing 1 per cent of all emissions. The size of the gap yawned over the three Icelandic siblings: impressive as they were, they disappeared in the grandeur of the landscape that surrounded it – the vast, open, volcanic expanse stretching kilometres in either direction as if to personify the forces that Climeworks was up against.[202] Nonetheless this startup leapt ahead and captured, much the most important, the attention of investors.

DAC machines can be built like Lego: pieces stacked on top of each other, in combinations of whatever size preferred. Both Global Thermostat and Climeworks followed this principle of modularity. But there was also a third pioneer, called Carbon Engineering, coming out of Canada. If the former two proffered small cars, this was the monster truck of DAC. It was established by David Keith, ideologist of removal and chief ideologist of geoengineering, whom we shall meet again in both capacities. Inspired by Lackner and the Thermostat duo, he opted for sodium hydroxide – the daughter’s choice – as an absorbing material and an unflinching 900°C to unload the carbon and a much more imposing plant architecture.[203] Eyeing economies of scale, some perceived Carbon Engineering as the true leader of the pack in the early 2020s.[204] It attracted very influential stakeholders.

This was the original triumvirate – Global Thermostat, Climeworks, Carbon Engineering – but after their respective demonstrations, a whole clan of startups begat their own models.[205] One report put their total number in late 2024 at 142.[206] Some looked familiar enough: the founding

father returned to the fore with a ‘mechanical tree’. Now at Arizona State University, Lackner planted the first exemplar on its campus. Where a normal tree would have a trunk, this one had a tower of metal; instead of leaves, it reached into the air with a couple of hundred discs daubed with a sorbent. Air would drift through and fill up the discs, which, after half an hour, would sink into a container. Steam would dispossess them of carbon and send them back up.[207] ‘This is the auxons coming through again,’ said the proud inventor, who claimed to have obviated the need for energy at both entry and exit points – a passive form of capture – and looked forward to mass production commencing in 2024.[208] But as of that year, there was still only the sole tree standing on the Arizona campus. The startup that had signed up to grow it as mechanical plantations, called Silicon Kingdom Holdings, was permanently closed.[209]

In early 2024, a wizardry outfit called Spiritus emerged from San Francisco to challenge the old-timers: its innovation consisted of a ‘squishy white ball’. The founder held it up before a reporter and squeezed it ‘like a stress relief toy. “And it has holes all over it that allow the CO_2 to go right inside.” Though it’s about the size of a tennis ball, its branch-like interior structure has a surface area equivalent to a tennis *court*, he said.’[210] Spiritus, though, preferred to call these little units ‘fruits’. It planned to manufacture millions and hang them on tree-like racks in a ‘carbon orchard’ in Wyoming.[211] Frontier promptly donated money. Skytree, a spin-off from the European Space Agency, used ‘porous plastic beads’ to seize hold of CO_2.[212] Finnish startup Soletair took a different approach to the problem of diluteness: going indoors. As we have seen, CO_2 circulates in much elevated concentrations inside crowded and closed spaces. What, then, could be more commonsensical than going after it in an office or classroom or factory? Soletair contented itself with killing two birds with one stone: removing CO_2 *and* improving labour productivity, studies having showed that cognitive function drops precipitously when the gas hits 1,400 ppm, as it easily does in airtight workplaces. Install a DAC machine among the computers or next to the assembly line and workers would become more alert as the CO_2 is withdrawn.[213] A more faithfully Drebbelian approach, it also reinvited the trope of the time machine. When the auditorium of a technology centre in Vaasa, the capital of the White forces during the

Finnish Civil War, was equipped with Soletair machines, visitors were offered a taste of nearly ‘pre-industrial air’, as the gas inside would be cut to levels prevailing in ‘Victorian times’.[214]

An even more precise operation might target shelter-in-place facilities.[215] Here the scenario would be for people sheltering from nuclear radiation or air raids to serve as fountains of CO_2; quarantines during future pandemics might come in handy. Or, micro-machines could be fastened onto drones intelligent enough to ‘sniff’ elevated concentrations in cities.[216] Picture the vehicles darting back and forth to catch the shoals of carbon. Or, put DAC on the roof of a nuclear plant for a good supply of heat.[217] Or, attach it to balloons that would go grab the carbon in the form of dry ice directly from the stratosphere.[218] Or, make use of trains, which whip up air. Insert a DAC car in between the regular cars and the air will run into the sorbent, no fans needed. This would be ‘rail DAC’.[219] There was a startup for that too.[220]

By the early 2020s, such companies were springing up like magic mushrooms, from Australia to Kenya, although with a distinct over-representation for the US.[221] In 2022, newcomer CarbonCapture announced the coming of the ‘Bison’, also to Wyoming, promising that it would be ‘the largest single atmospheric carbon removal project in the world’ by 2030.[222] Shortly after, however, the founders admitted that they were behind schedule. ‘We have been just a little bit naïve about all of the work that needed to go into getting something ready for us to put carbon dioxide downhole.’[223] Infinitree tried (apparently with little success) to stay closer in spirit to Lackner’s passive style.[224] Needless to say, there was an Israeli company too, and it called itself RepAir, and it tried out a DAC machine the size of a shoe box.[225] Avnos plucked not only carbon but also water out of the air.[226] Svante took its name after Arrhenius.[227]

As of 2024, this clan had managed to put up a grand total of 27 DAC facilities in the world.[228] That was 26 more than the BECCS plants. DAC was now, for reasons we shall soon explore, the negative emissions technology surrounded by the most intense hype by far. Everything suggested the near arrival of more startups, novel sorbent types, new and improved arrangements, the next generation of ultra-smart devices. As we write this, the news is just in that scientists in Oregon have discovered that CO_2 falls particularly rapidly for the chemical element vanadium.[229] But

the professor in charge would probably not have called it a liquor: ‘It’s not a magic elixir. It’s new science. It’s a new approach. It’s a new tool.’[230]

The bourgeoisie ascends to heaven

This catalogue has no end. ‘What if excess carbon dioxide could be sent into space?’[231] Elon Musk offered his rockets in response.[232] What we have done here is merely to provide a sample of the constantly self-renewing ideas shooting out into this space. With such a supernova of innovation, the capitalist mode of production has evidently activated its whole fabled and fabulous ingenuity; once more, it is showing us ‘what man’s activity can bring about’.[233] All that has melted into the air can be made solid again. A shortlist of company names – Terraformation, Living Carbon, Charm Industrial, Rewind, Brilliant Planet, Planetary Tech, Spiritus, Infinitree, RepAir and, of course, Global Thermostat – suggests that the bourgeoisie, or at least an energised fraction of it, has sublated its old spirits and resolved to redeem itself. If not exactly a *mission civilisatrice*, this is surely no less than a mission to save human civilisation, the most exalted crusade this class could launch. And ought we not to be grateful to it? How else would we engage in carbon dioxide removal, if not by trying out every tool it throws our way? What is needed if not precisely the infinite engineering capacities for which this mode of production is known? Surely some of these tools must work; and if not today, then those fabricated tomorrow. There is comfort in the thought. If we have any chance of stopping and reversing, it must be located somewhere around here. This is how we face the reality of climate breakdown and ward off the tipping points and back out of the age of avalanches … Or, have another squeeze on the stress relief toy. A less sanguine reading of negative emissions technologies is possible. It, and any serious consideration, begins with the problems and precarities of each.

9

(… and the Appendix of Caveats)

Every item in the catalogue has an asterisk pointing to whole sections of second thoughts. Side effects, inadequacies, drawbacks, limitations, risks, potentials for conflict pile up in an appendix written in small font under the bombast of the startups. The question raised here is, again, the most basic one: will any of this work? Can the floated technologies actually peel back CO_2 concentrations? They may prove incapable of taking out enough of the gas to return to lower levels. If all they can do is inhibit a further rise, the world could be stuck with 1.5°C or 2°C or any other average temperature increase, even if the technologies work around the clock at full capacity. Then the problem would not be the difficulty of undoing damage after tipping points. It would consist in the practical defencelessness against it.[1] And what if the technologies turn out to be unfit even for this minimal defence: what if their combined prowess fails to make any meaningful difference to the amount of CO_2 in the atmosphere? It could all just be a castle in the sky. Then the world would be trapped in the self-perpetuating avalanches with no way out.[2]

The determinant factor is scale. A technology that can, at most, nibble away a few tonnes of CO_2 will be of no use. To make a dent in the curves and lines, it would have to scale up to, initially, the gigatonne level: the unit that puts a stamp of relevance on a candidate. Because so much CO_2 has accumulated in the atmosphere, a counterforce has to reach corresponding immensity. One does not empty a bathtub with a teaspoon, especially not if the tub is overflowing and danger is on the very rapid rise. Not even drawers full of teaspoons will do the job. Most visions for removal hinge on

a ‘portfolio’ of utensils: some forests, some BECCS, a bit of enhanced weathering, a slice of DAC, in proportions to be determined; but even then, each must contribute gigatonnes.[3] The parameters of the arithmetic are fairly uncomplicated: if the world economy keeps emitting 40 gigatonnes of CO_2 per year, as in the early 2020s, temperatures will exceed 1.5°C and 2°C before long; and if (and this is a big if) emissions are then finally brought to zero, a suite of negative emissions technologies would have to be able to take down tens of gigatonnes to cancel out the intervening overshoot. In its report from 2022, the IPCC mostly envisaged upwards of ten gigatonnes every year by 2100; but depending on the size of the overshoot and a host of other variables, some models predicted far more.[4] The Special Report on 1.5°C suggested that a cumulative total of one thousand gigatonnes might have to be drawn down over this century.[5] All of these are ballpark figures. They can have no precision, merely hint at the magnitude of the challenge: for removal to work, it has to skyrocket above the mega-scale and reach the giga and tera. The outer limit here is the 2,500 gigatonnes of CO_2 emitted between 1850 and 2022.[6] One might want to remove all of this to return to the baseline. But that figure grows, of course, for every consecutive year.

And the scale pressure grows in tandem. More of the negative is demanded for every positive addition. By the same measure that positive emissions necessitate negative ones, they require of them titanic capacities, and it is here that they must move out of their proofs of concept, beyond the tightly controlled system boundaries of a lab or model: can they live up to the gigatonne claims in the real world? What would that take? What kind of sacrifices would have to be made, what fallouts activated? Had we needed but a spoonful of removal, it might have been easy to pull off. But the scale of the matter means an abundance of ways in which things can go terribly and terrifyingly wrong.

What comes naturally

In words untypical for the journal *Science*, two authors in 2020 commented on ‘the widespread obsession over planting trees’, the technique at the core of natural climate solutions.[7] We have seen some of the reasons for this

obsession: planting trees is cheap; it sounds jolly, like going on a school outing or taking a spa day; everyone knows how to do it. Indeed, it already happens in the real world, more than any other form of removal. Of all the carbon drawn down by human hand in the early 2020s, 99.9 per cent came through the planting or managing of trees. The contributions from BECCS, biochar and the rest of the catalogue were so insignificant they barely registered.[8] Affirmative action for the forests of the world removed about one half of one tenth of a gigatonne per annum, in the lowest estimate; just over two in the highest.[9] The vast bulk of those trees were set out for unrelated reasons – people plant with purposes other than carbon dioxide removal – and unending deforestation overshadowed their contribution by releasing another four to seven gigatonnes each year. But the quotidian nature of the practice lent it credibility at first blush. Tree planting would just have to be made purposeful and gargantuan and gallop around the earth at top speed: and according to the most optimistic estimate, the planet does have room for extra canopy cover storing some 800 gigatonnes of CO_2.[10] A more mid-range guess gave natural climate solutions the potential to take out a total of 400.[11] A typical upbeat calculation assigned them the theoretically possible task of doing ten or twenty every year.[12] That would mean increasing actually existing removal by anywhere between five and 400 times. Might such a ramp-up come up against obstacles?

A speedy turnover of land to forests could cause emissions to initially spike, when hands and implements rummage through the soil and trucks transport seedlings; it would take some time for the effect to be annulled.[13] A more enduring problem is that of albedo. Trees capture carbon, but they also alter the colouring of the land. If spruces are planted on plains covered by snow in wintertime, less sunlight will be reflected back into space. Converting a wheat field into forest turns that patch of Earth from bright yellow to deep green. Where the drop in albedo is sharp, it counteracts the impact of removal on the energy balance of the planet, the trees giving as much heat with one hand as they take away with the other.[14] Whether this happens depends on the local background conditions, the reflexivity of the surface on which trees are grown; traditionally, boreal regions have been seen as the worst choices. You do not want to exchange snowy ground for thickets of dark conifers. This is one reason why would-be planters have turned their gazes towards the tropics, where brown land could be swapped

for green.[15] As the snow retreats from the north in a warming world, the gradient of albedo change between higher and lower latitudes is diminished; but the problem extends beyond snowpacks. Deserts, for example, are very light and repel much of the sunlight they bathe in. Making them bloom, from Arabia to Atacama, would reap carbon from the sky; but the reduction in albedo could overtake the cooling impact. Irrigation and afforestation of deserts might bring refreshing shade to inhabitants during the hottest midday hours: but it could make the planet as a whole even hotter.[16] Enrobing the Gulf in greenery could compound its contribution to the heating. Albedo reduction shaves off the gains in drylands of other types, in grasslands, savannas, shrublands and, according to recent findings, even in some tropical areas.[17] All of the removal effect might be lost, or half of it, or one third.[18] But the optimistic estimate – the 800 gigatonnes – simply ignores this penalty and locates half of the supposed potential in drylands, in places like Sahel and Saudi, where tree planting might in fact be counterproductive. If the problem is accounted for, the available land area shrinks by up to three fourths.[19] And this is not even the main worry.

We have seen how regimes of disturbances are changing: heat stress, dry periods, firestorms, hurricanes, defoliators and other agents scything through forests are aspects of the warming itself.[20] Take the fires. In 2023, Canada's worst wildfire season so far consumed parts of the BigCoast Forest Climate Initiative, a project selling carbon offsets on the promise to keep trees standing, a glistening package of natural solutions from the shores of British Columbia: up in flames and smoke. This came two years after nearly one tenth of the Darkwoods offset project in the same province met the same fate.[21] Across the border, at least half a dozen similar ventures in Washington, Oregon, California had fires running through them during the second half of the 2010s.[22] Microsoft saw some of its purchased offsets burn. So did BP.[23] The charred forests were supposed to help bring these companies to net zero. Providers normally deal with the risk by maintaining a 'buffer pool': they sell slightly fewer offsets than they have trees for, keeping some in reserve to compensate for any loss to acts of God. But the warming is eating into the buffer, and more. In just one decade, wildfires consumed almost the entire pool set aside by the Californian offset industry for the next one century. Assets could no longer be left idle, meaning that actually capitalised trees were burning too.[24]

When Microsoft or BP buys credits from a forest, their intention is not to reverse climate change. But any such intention would run into the same problem. Indeed, full-throttle removal would put a premium on the tree species that grow fastest – eucalyptus, pine, hybrid poplar – and pack them together in thick stands.[25] Trees that take a century to yield the desired removal would be of scant value.[26] Giving forests back to autonomous nature and letting them rewild at their own discretion one scattered bush at a time would be maddeningly inefficient: there is no way it can attain the aspired scale.[27] The job assigned to natural climate solutions will push them in the direction of monoculture plantations. But these are also the kind of forests most prone to catch fire, stacks of highly flammable timber served up to the rising heat.[28]

The best-case scenario here is that of an arms race, in which the build-up of carbon in tree plantations would catch up and overtake the build-up of carbon in the atmosphere before the nodal lines to forest collapse are crossed. Given the self-organised criticality of most biomes already in the 2020s, however, this seems like an uncertain bet. The problem of disturbances is bound to grow over time, the firepower of the atmosphere to rise.[29] Shielding forests against it by means of satellites and water bombers and other fire-suppressing technologies would be self-defeating: it is well known that overzealous exclusion of fire yields the opposite effect.[30] The worst-case scenario is that of plantations succumbing to the accumulated pressure and going off like firebombs and sending fresh pulses of CO_2 into the atmosphere, the defence lines against feedback mechanisms defecting to their camp.[31] The risk spans every region identified as a promising zone for forestation, from California and the Amazon to, of course, the ultra-hot Gulf.[32] It applies to other kinds of forests and impacts as well: mangroves are vulnerable to sea level rise.[33] ‘Natural climate solutions are solutions at risk from the problem they are attempting to solve.’[34] It is like trying to cure Alzheimer’s disease by thinking more often about what happened yesterday.

None of this will be helped by photosynthesis enhancement. If a genetically modified plant stores more carbon, it holds more fuel for the fires.[35] (But one should perhaps not rule out the possibility that some wizards of California will come up with albino plants to manage the albedo problem. Perhaps the present authors should have dashed off to patent the

idea and get rich!) To the disturbances must be added the temptations to cut down trees: there can never be full assurances against the next generation using the wood or clearing it out for whatever purpose.[36] Already, illegal logging in forests used for carbon offsets is not unheard of.[37] Possibly there could be heavily patrolled and fortified carbon parks. A certain brutality inheres in the very notion of natural climate solutions, because it presupposes the swelling of a scarce resource: land without people. All those trees must have ground to stand on. But there is not much terrestrial space that is not somehow utilised and populated, which means that the people living off or on the land might have to be transferred for the trees to sprout – especially if there has to be very many of them.[38] The article from 2017 that launched the career of natural climate solutions counted on the disposal of a land surface area larger than that of the US, Canada and Russia combined.[39] Removing one single gigatonne per year through forestation might require two whole states of California.[40] Where on Earth is this land going to come from?

Natural solutionists have turned towards the tropics, because of a manageable albedo problem and high primary productivity – jungles shooting up to the sun – and, by the by, 'land is relatively cheap and available'.[41] It could be gotten for a song in Congo or Colombia; not so in Florida or Flanders. A team of Dutch IAM modellers would report that 'afforestation causes a larger share of total negative emissions to be located in low-income regions' – and how could it not? Cost optimisation could not produce a different result.[42] Paving over the city of London with pine plantations would be prohibitively expensive, but less attractive real estate was fair game. The optimistic estimate – the tantalising 800 gigatonnes – commandeered vast expanses of inhabited land in the global South, including the entire city of Kinshasa, population 16 million.[43] That particular estimate was compiled by scientists based in Zürich, Rome and Montpellier. It was not a case of scientists based in Zanzibar, Rabat and Maputo assuming that the 17 million inhabitants of the Netherlands could be expelled for tree plantations. It was the coloniser's eye scanning the globe for opportunities: behind the human face of removal, the spectre of the Great Dying. The idea of making up for emissions from the global North by planting trees has, as we have seen, had a colonial streak from the

start. It was not surprising that someone like Donald Trump chimed in on the jargon.

What is land used for, if not for removing carbon? Commonly for producing food. That activity would have to move over, with predictable results. Using afforestation to take out 800 gigatonnes by 2100 would cause food prices worldwide to quadruple – the kind of figure, generated by one modelling exercise, that indicates the troubles in store.[44] There would be 'drastic impacts on the poorer part of society', rather an understatement.[45] The Dutch IAM modellers found that afforestation for staying at 2°C would push 441 million people in the global South into hunger – it might as well be 341 million, or 941 million; the point is clear enough.[46] Planting trees in sufficient numbers to keep warming in check would starve propertyless masses. Bullish assessments of what natural climate solutions in general and forestation in particular can accomplish tend, again, to overlook this little detail.[47]

The same goes for water. Plantations are as thirsty as they are hungry for land, inclined to dry up streams and deplete groundwater and lay claim to sources otherwise used by humans.[48] Desalination will not escape the trade-off – every quantum of water would be allocated to trees rather than people, who might be citizens of the most dried-out nations – although it would have the added benefit of countering sea level rise.[49] To grow fast, trees will need land plus water plus fertilisers in enormous quantities, the nutrients from which might run into streams and exacerbate eutrophication and widen various metabolic rifts, the defensive capacities of ecosystems worn down further.[50] Biodiversity would lose out. Monocultures are just that.[51] Contrary to the win–win reputation, neat rows of fast trees would smother fauna and flora, particularly on grasslands. African elephants will fare no better than the people of Kinshasa if their lands are covered by eucalyptus plantations under 24/7 guard, and these are no mere idle speculations: the northern solutionists have eyed the great savannas of Africa as a land without trees. The planting is already underway.[52]

One could decide to go with the wildebeest instead. One could cut out the monocultures and root for the wild. One could stop the logging machines and let forests regenerate by themselves and allow them to grow old and diverse and design every intervention in such an unintrusive manner that only the most benign effects on wildlife are realised.[53] One could respect

every prior use by humans. And one could apply these principles far beyond the realm of trees: scrap the fields of suberin crops, decommission the ploughs and pesticide aggregates and make food production abide by the laws of nature – agroecology with perennial plants at its deep-rooted core.[54] Here, in many ways, was the gold standard of removal: let the flow of negative carbon come about by itself, a serendipitous side effect of efforts to protect ecosystems for other reasons. (Supposedly, it was this model that the likes of Monbiot had in mind.) But to the extent that such high standards are respected, natural solutions will lose their ability to do anything much about climate. Virtue and quantity are at variance. Assessments that exclude patently destructive forms of tree planting end up with a potential for an annual rate of one or two gigatonnes and a cumulative total of 100 to 200 – fractions of the brasher figures.[55] This would not be nothing, but it would also not be much. It bears repeating once more that the capitalist world economy in the early 2020s gushed out another 40 gigatonnes every year, with no sign of letdown; in what looks like the very best case, solutions honouring the needs of humans and non-human nature could down five years' worth of such emissions *in absolute total*. Then their operation would have to be declared over.

At the root of this regrettable arithmetic is the nature of fossil fuels. They hold carbon from millions of years of photosynthesis compressed in chunks and fluid; as they are set on fire, that deep legacy is disembowelled all at once. The idea of natural climate solutions is to make photosynthesis on the surface of the earth bring back the CO_2 thus released. But this is like expecting an ordinary fire extinguisher to be effective in dealing with a nuclear bomb.[56] There is a fundamental incommensurability between emptying the passive carbon cycle into the atmosphere and galvanising the active cycle in the terrestrial biosphere: the two can never match in scale – even less so because the former has been ongoing for a couple of centuries, while the latter needs to happen in the span of a few decades.[57] For trees to get some punching power against the overaccumulation of CO_2 above, they would need to knock down all humans and other species in their way; but even that might not be anywhere near enough. One major fossil fuel producer in the global North, which also happens to have plenty of room for trees, illustrates the predicament. Maximum possible forestation in Norway would take out as much CO_2 as is contained in one single year of its oil and

gas exports.[58] And these exports are set to continue next year, and the next … Overshoot steadily aggravates the scalar asymmetry.

Most ineffectual of all would be trophic rewilding and similar eminently agreeable schemes. Herds of wildebeest or wolves or elephants will never claw back any significant amount of the CO_2 vented by fossil capital.[59] Whatever effects they have on the carbon cycle is 'highly uncertain and context-dependent', one team of ecologists warned. Pretending otherwise and continuing to see large animals as little more than walking carbon removal devices could lead to 'bio-perverse outcomes'.[60] And even if – a genuinely utopian scenario – all the losses of wild nature since the early nineteenth century were to be reversed, it would take us back only to the baseline of land use change and undo emissions from deforestation. But it would have no bearing on the CO_2 mobilised from under the ground. Forests cannot put it back where it belongs, because once they have regrown, their capacity for removal is exhausted.[61] As a time machine, their potential is strictly limited. This is the case for abandoning flower-power notions of nature and strapping on some hard, non-stop, mechanical pumping mechanism on nature and driving the CO_2 back down into the lithosphere. Prima facie, that case is a strong one.

Plotting bionecropower

BECCS would overcome the problem of sink saturation by continuously looping CO_2 into the ground, but it would stay trapped in dependence on land.[62] Where on Earth is all the biomass going to come from? You would not want to raze old-growth forests to make room for plantations of eucalyptus, willow, switchgrass, silver grass or some other fast-growing feedstock, because however fast they grow, it would take time to make up for the carbon lost with the ancient trunks and soils.[63] You could not rely on 'marginal land', a residuum sometimes invoked in modelling, on which fertility by Ricardian law is lower.[64] You would want the best land where the plants can freely flex their muscles.[65] The signs point towards prime agricultural land – here too, yields will fall in a warming world, the fields and pastures struggling to give as much as they used to; but this is perforce

where a great deal of the supply would have to be found.[66] Earth has no undiscovered continents left. ‘We now inhabit a “used” planet,’ meaning that for BECCS to get off the ground, some existing uses would have to be discontinued.[67] Here too, food production would have to step aside.[68]

How much ground are we talking about? Once the BECCS rabbit had been pulled out of the IAM hat and leapt into the IPCC scenarios and set the wheels of overshoot running, scientists began to ponder the land area required to make this whole thing a reality. The Panel banked on BECCS removing anywhere between three and 20 gigatonnes per year, up to a cumulative total of a median 600 this century, so as to keep the heat down to 2°C or less – sums that would then have to be converted into area size.[69] One study found that one third of total arable land in use would be needed, as much land as half the US.[70] Another landed on one and a half times the US.[71] Some said one or two Indias; some nearly one tenth of the earth’s surface; some one fifth of all net primary productivity currently appropriated by humans.[72] Several teams concluded that the equivalent of total current cropland would have to be allotted to BECCS plantations to carry the assumed burden.[73] These figures were mind-boggling, not only for the absolute sizes they gestured at but also for the speed of the rollout: this would have to be the fastest conversion of land ever seen. In the early twenty-first century, soybean plantations swept away other types of land use at the highest rate recorded in history; but BECCS would have to do it at least three and perhaps ten times faster.[74] Scientists outside the IAM hubs were looking at these numbers with rising panic. What the models were suggesting was the equivalent of drunkenly driving a bulldozer back and forth over the world’s farms (and some remaining wild forests thrown under too). Here was overshoot ideology in its purest distillation.

In the sphere of policymaking, this procedure precedes, it is worth noting, any presumed reversal of climate change. Governments have already started setting aside land to meet their current pledges. These usually stretch only halfway into the century. To become net zero by 2050, a nation may announce that it will dedicate this or that number of hectares to planting trees and bioenergy crops; anticipated removal will then be deducted from expected emissions, the negative and the positive evened out. As of the early 2020s, the governments of the world had already mortgaged two thirds of the total area of cropland on Earth – not to cut temperatures, but to

offset what could not be subtracted from business-as-usual and reach the goal sum of zero. Almost half of this hazily visualised extra land would come in the form of plantations, although not even one tenth for BECCS.[75] The pledges tallied up to a doubling of the land used to grow stuff for humans, and this only for getting to net zero by mid-century. Aspiring climate restorers would need to dip far below that in the ensuing half-century to make the negative outweigh the positive; such is the pitiless arithmetic of overshoot-and-return. How much more would governments be ready to earmark for this? The post-Paris net-zero ballyhoo did not suggest caution or restraint when parcelling out land for removal.

For BECCS too, the working assumption was that land would be dished out from the South. 'Models universally project that the majority of biomass supply for bioenergy and bioenergy consumption will occur in developing and transitional economies,' the IPCC matter-of-factly reported in 2014.[76] The reasons for this universal projection were the same as in the department of forestation, and here too, it was a case of producers of science and ideology in the global North talking to themselves about how land in the South could be used. Southern voices were almost completely absent from the chatter about BECCS.[77] Some might find it a tad unfair that the North draws up plans for the South to give up land mass to recapture gas the North must pass.[78] The sacrifice concerns sustenance: there would have to be a switch from the metabolic needs of human bodies to those of power plants, and most of it would happen in sub-Saharan Africa.[79] Skipping the euphemisms, poor black people were here expected to starve so that rich white people could reinsert their gases into the lithosphere.

But that would not be the end to the exploitation, because BECCS would contain a moment missing in forestation: the production of an exportable commodity, namely fuel for power generation. While supply of land is assumed to be largest in the South, demand for electricity is strongest in the North, and so models intimated a chain running from plantations in, say, Cameroon to plants in, say, the UK to final storage somewhere under the North Sea.[80] The biomass would be grown in the peripheries where land is abundant and ferried to the core where money is concentrated for burning and burial. As a purely incidental byproduct of the modelled arrangements, the North would seize yet another useful resource from the South in the process of removal. The screwing over of the darker nations here appears to be never-ending: first the paler regions would inflict on them the mass

suffering of climate change in excess of 1.5°C; then their land would have to be reallocated from food to BECCS plantations to make amends for the overshoot; meanwhile, the bioenergy would benefit the original centres of profligacy. Who on Earth could have dreamed this up?

There are a couple of concrete precedents in fresh memory. Between the invasion of Iraq and the financial crisis, the US and the EU ran a stimulus programme for ethanol and other biofuels. Corn was sent off to cars instead of kitchens; grains were diverted to combustion in engines, fields from Brazil to Malaysia given over to the feedstocks. Farmers around the world were made to abandon their usual edibles. In 2007, 'thousands of rice and maize farmers' in Tanzania were 'evicted from their lands in order for large companies to plant sugarcane and jatropha trees (whose seeds are a feedstock)' – it can be done.[81] Global food prices nearly doubled in less than a year. Such a shock could be absorbed by wealthy households spending maybe a tenth of their income on food, but not by those spending half and having children already on the verge of malnutrition. In 2007 and 2008, food riots circumnavigated the global South, with crowds from Haiti to Egypt to Bangladesh going on strike, seizing shipments, occupying markets, looting shops and fighting cops.[82] The biofuels boom was not the sole cause of this season of hunger and rioting: extreme weather events in several breadbaskets were another.[83] Both factors are likely to be magnitudes larger if BECCS lives up to the modelled expectations later in this century. After the crash of 2008, financial capital streamed into the production of agricultural and other commodities in the global South, prompting a land rush on a scale not seen before – again, a limited rehearsal for what BECCS would look like if the projections come true.[84]

Or one might see a precedent in the eucalyptus and pine forests planted on top of Palestinian villages erased during the Nakba. After 1948, the Zionist entity compulsively and methodically blew up remaining houses, chopped down olive and orange and fig trees and established monocultures imported from Europe to cover up its deeds (some of those pine trees would have been the ones sunk by Rewind into the Sea of Galilee).[85] One could even find such erasures still at work in the core of the North. In Sweden, the onward march of monoculture plantations and stubborn clear-cutting practices continued as usual in the early decades of the twenty-first century, eating away at the country's few remaining old-growth forests. The main victims were the indigenous Saami, whose herds of reindeer would find

little nourishment in the depleted landscapes.[86] One could, indeed, look back on the entire history of enclosure and related forms of primitive accumulation as precursors to BECCS. Were this technology to materialise at the modelled scale, it would set off one more global wave – perhaps the largest and last – of separations between people and their means of subsistence. Following the latest price hikes announced on the market, smallholders would be driven off their land to join edgy crowds of slumdwellers. A few might become proletarians tending the mechanised plantations.[87]

But none of this might, of course, come to pass. All is at the level of hypothetical scenario, computed and illustrated a priori. This is not enclosure executed at gunpoint: it is appropriation as fantasy. It is expected to come, not with brazen greed or the zeal of ethnic cleansers; couched in technical neutrality, it is merely the sum of the calculations performed by the IAM machine. Yet it has something distinctly dreamlike about it. So far, BECCS is essentially a psychic exercise in wish fulfilment, in which latent content from the earliest days of primitive accumulation all the way up to the residues of recent years is condensed. Like a dream at night, it 'enacts something as immediately present, *dramatises* an idea' – the idea that mass appropriation of land could fulfil the wish for removal; and because they emerge from a computer, key elements of the dominant classes in the global North have been prepared to 'accept the hallucinations in good faith'.[88]

When governments set aside an area equivalent to two thirds of total cropland on Earth for their net-zero projects, there is no guarantee that their efforts will ever become reality. The same goes for every BECCS projection. If the appropriation does not make the transition out of fantasy, the removal will not take place, and there will be only the avalanches.[89] That would be bad enough, but there is another twist to the dialectic of fantasy and reality in a warming world: because BECCS has been the centrepiece of all models for overshoot-and-return, the one technology that has allowed 'policymakers' to postpone emissions cuts, totally dominating IAMs and scenarios in the years of Paris, *the ugly fantasy of appropriation has already contributed to the grim reality of climate breakdown* – one reason we are in the age of avalanches, in other words, being the dream of BECCS itself. Bourgeois society hallucinated about solving the climate problem by engaging in its most time-honoured practices on the land, only to thereby let it get out of hand.

If BECCS does step into the real world – and there were, as we have seen, preliminary indications of this in the early 2020s – it could happen solely through the exercise of power over people. It would be tempting to call this 'biopower', but the purpose would not be control over human bodies in the Foucauldian sense of the term. Rather, it would be the enabling of a particular technology: people would have to be subjugated and dispossessed for the BECCS machine to arise. The ultimate value of the biological material would be realised not in life, but after death. It is the necromass from BECCS that motivates the idea – the bioenergy a bonus – as its burial will negate the effects of burning dead matter from under the ground. This is a technology for managing death as much as life: perhaps we may speak of *bionecropower*. We might, furthermore, hypothesise that any removal based on photosynthesis – natural climate solutions included – would call forth this modality of power, as certain relations between people and land would have to be instituted for the forces to do their work.[90] An attendant form of politics would then develop, with subalterns likely to fight back against encroachment and immiseration, recycling forms of collective action from past repertoires, with the fate of carbon now at the centre of contention. More concretely, what would farmers in Cameroon do if large companies show up to evict them for eucalyptus plantations, so as to produce biofuel for British people and take their emissions out? What if they are herded into towns on the brink of hunger? In 2008, the cities of Cameroon exploded in food riots, as crowds marched with placards saying 'Hungry Man is Angry Man' and then fell to bullets in the hundreds.[91] IAMs have not represented any such events, but they may well come to shape the character of BECCS as a coercive apparatus, or a monumental failure.[92]

There might, however, be a way to save BECCS from this dystopia. Some have pointed to one type of land that could be ceded to plantations without detrimental effects on livelihoods. That would be land for industrial-scale rearing of livestock – think cattle ranches in Arizona or the Amazon. Sourcing nutrition from animals is an absurdly inefficient use of land area. It takes about 100 times more of it to produce one gram of protein from beef or lamb than from beans or tofu.[93] More than two thirds of all agricultural land on the planet is pasture; of the remaining cropland, nearly one third is used to produce fodder.[94] Nothing so determines land voracity as diet. The average beef-heavy American fare requires six times more land

than the plant-based counterpart in India; if all humanity were to adopt the former, 98 per cent of terrestrial area would have to be used up, including deserts and frozen antipodes – a physical impossibility.[95] But unfortunately, humanity has been moving in precisely that direction for about half a century, as more and more people – particularly in China – seek to eat like Americans. Overtaking population growth in country after country, this turn to meat is becoming the major driver of land use change, causing forests around the world to fall to cattle ranches.[96] But what if the trend could be reversed?

It has been argued, since the early days of the BECCS hype, that a transition from meat and dairy to plants could redeem the tech.[97] Here is the only continent available for annexation without starvation. Shifting human metabolism away from animal products would free up space for the trees: according to the most recent study, as of this writing, replacing half of such products with vegetable alternatives could let them remove up to 10 gigatonnes per year. Replacing all of them would permit BECCS to draw down 700 gigatonnes in seven decades.[98] A plant-based diet is the secret door that leads out of the cramped planet, away from trade-offs to actual win–wins: it would eliminate the methane emissions from enteric fermentation – the farting and burping cows – and remedy the epidemic of obesity and associated diseases issuing from the self-harm of meat consumption.[99] But this too, arguably, would be a form of bionecropower. People who eat meat tend to love it and resist the idea of desisting. In vitro meat might go some way to satisfy the cravings; but a segment of consumers might spit it out. More forceful means than supplication may have to be employed to realise these potentials. One could begin by abolishing the entire meat industry in the US and consigning all its rangelands to BECCS – an apt overture to removal. One might want to go easier on the herders of Mongolia, whose diet is also, for different reasons, heavy on meat (indeed, much pasture used by pastoralists in the global South is ill-suited for growing crops and so should not be considered for BECCS, which would take food out of their mouths). One would certainly have to confront all the capital invested in the contemporary meat industry, an enemy not so different from primitive fossil capital: this would be less enclosure redux and more ecological war communism. It would entail some degree of coercion.

Not even the most perfectly vegan economy of BECCS would, however, escape some other constraints. The risks of fire and other disturbances remain. Climatic impacts on the land might throw the whole enterprise into jeopardy. Because of falling fertility, a warming of 2.5°C could make the effectiveness of the technology plummet: beyond this point, the 'yields of agricultural residues for BECCS would be too low to meet the Paris goal of 2°C, even by 2200'.[100] Whatever land use the plantations have replaced, they will be sensitive to peak warming. Only at relatively low temperatures can they be expected to throw off all the needed biomass. Put differently, the success of BECCS is fundamentally dependent on that of mitigation – on the absence of any substantial overshoot. It would be funny if it were not so ironic and tragic. The very thing that the technology is supposed to palliate debilitates it: the Alzheimer paradox again.

And then there are the other familiar downsides, likewise unaddressed by a protein transition. There is the waste of water. A biomass plantation demands more than twice as much freshwater as the average agricultural pursuit.[101] This resource will, we know well, become ever more precious as climate change bites harder. But if BECCS is deployed for returning to 1.5°C during this century, the number of people suffering high water stress might double – from two to four billion – and the induced scarcity exceed that caused by global warming itself.[102] Whether they supplant cattle or cassava, plantations would have to be soaked in fertilisers. The equivalent of up to three fourths of all fertilisers used in the world in the early 2010s might have to be sprayed on BECCS; or, in another estimate, twenty times the amount used in the US in an average year.[103] Biodiversity loss is a foregone conclusion. Under certain scenarios, as many species might disappear due to this technology as to, again, global warming itself.[104] The frogs of Central American mountains, for instance, will not appreciate a vista of willows. If overshoot-and-return happens through a good deal of BECCS, animals re-immigrating from their refugia might find their paths or homes transformed into bioenergy deserts.[105] Just how bad the losses would be, however, depends on the richness of the prior land. If the plantations are carved out from wild forests, they would be disastrous; if from ranches, possibly trifling.[106] But losing less is not, of course, the same as winning. A minimum concern for the other creatures on this planet would aim to increase their habitats above the collapsed baseline. Imagine we really do

win the war on ruminant capital: why then would we give the freed-up land to yet another ravenous industry? One could certainly do more pleasant things with it.

Now it's worth noting that if Stockholm Exergi or Drax finally turn on their capture devices a few years from now, the biomass will not come from land seized from livestock or people. They will not feed them with trees set aside specifically for that purpose, but rather lean on industries that are already in place. Might there yet be a non-vegan route to sustainable BECCS in this? Sticking capture devices onto existing bioenergy plants would seem to promise negative emissions without the need for (much) extra land. There was indeed some potential here, but in the larger scheme of things it would not get you very far: few countries already burned large amounts of biomass (Sweden being one of the exceptions), and it would be a stretch to call such burning sustainable.[107] And there was another problem. If BECCS was dependent on extant forests, any diversion of that supply into its furnaces would need to be deducted from the natural side of the removal ledger. Capturing CO_2 in this way would at best make the process carbon neutral – the CCS offsetting the combustion of what until that moment had been a standing carbon sink.[108] Any negativity would occur later, when new trees had atoned for the debt incurred in the initial harvest. Specialists called this the 'carbon payback' period of bioenergy use, and for any material derived from forests, it stretched decades into the future.[109] In other words, at the moment when BECCS was first switched on, its removal qualities would be purely aspirational. They would become material only when trees had been replanted and after they had matured and successfully navigated the many dangers of the long heat, like a pilgrim in the City of Destruction. Not just climate change but time itself here intervened: the neutral and negative moments of BECCS lay decades apart. And because those decades look poised to be so very eventful, a straight line between the two moments demarcating them and safe arrival in the Celestial City could not be guaranteed.

One way out of this was to rely on sources of biomass with a much shorter carbon payback period: agricultural residues, or short-rotation grasses such as *Miscanthus*; or wheat straw, or food waste, or livestock manure. This was the path trodden by at least some of the pioneers. But there was only so much residue lying around, only so much usable shit; and

BECCS was far from the only industry eyeing its use.[110] Before long you would find yourself in need of growing some more: and then we would be back to square one, with the question of land. Perhaps one could cap the plantations to make them align with the limits and impose additional commandments – such as, be frugal with water. But avoidance of extra water stress might cut down capacity to less than one gigatonne per year.[111] Also limiting nitrogen pollution and ensuring 'biosphere integrity' could bring it very close to zero.[112] Other assessments of the risks converge on a similar recommendation: don't try to do more than one.[113] The scope for non-destructive BECCS, it seemed, could not be counted in gigatonnes in plural. But one would be an utter pittance.

We are here back at the inverse relation between acceptability and performance. The lower the adverse impacts, the more genial a negative emissions technology; and, by the same measure, the more limited its scalability, the lower the total potential.[114] At a certain point, depending on the amount of CO_2 in the air, the demand for scale may compel the technology to become so extreme as to render it infeasible in absolute terms.[115] By the early 2020s, just as the first plants outside of Illinois began to take shape, the extremism inherent in BECCS had brought it into scientific disrepute.[116] That hopes for humanity were pinned on this technology for two crucial decades and evoked to excuse another few rounds of business-as-usual – that this could be made the very core of programmatic overshoot – now come across as an epic fit of madness, albeit one fitting for the times.[117] Whatever limited future BECCS might have, it has already done its part in deepening the damage.

Ration the trips

Could biochar make us happier? Ayahuasca for everyone might create problems: take *terra preta* out of context and scale it up to climate-altering levels and side effects may begin to show. While biochar is compatible with and indeed beneficial for agriculture at the smaller scale on which it has traditionally been practised, multiple gigatonnes are another matter.[118] Where will all the organic material come from? The kitchen middens of

towns and forests might not be enough to feed a pyrolysis machine of such size: there would need to be specially designated lands for biomass cultivation, bringing in their wake the by now well-known troubles.[119]

Or, one could scour the planet for decaying plant matter and scoop it up for biochar applications. But plants decay for an ecological reason. They circulate nutrients back into the soil, feeding all the life forms that hide there. Withdrawing a substantial part of this material in the name of repurposing and optimising 'waste streams' brings to mind Donald Trump's infamous proposal to rake the country's forests so as to prevent the inconvenient wildfires that plagued his first presidency.[120] It would retrigger the original metabolic rift, as nutrients would be robbed from soils in a desperate drive to funnel carbon out of the atmosphere. Every other idea in this section of the catalogue – wood vaults, bio-oil, human shit, what have you – risks running into the same cul-de-sac. Either it would have to adopt the principle of plantations, or it would have to make do with the scraps from photosynthesis and tear apart the metabolic cycles in which they revolve. In the case of the sewage sludge of Los Angeles, the proposal was in effect to revive the original rift by stopping the recycling of the nutrient content of human waste to the land and burying it underground instead (possibly leading to reinforced dependency on synthetic fertilisers from fossil fuels). Repurposing the contents of latrines for removal might prove unpopular too: one startup in New York state sought to make biochar out of 'human biosolids' but was booed out of town by residents who refused to put up with the anticipated filth and stink.[121] But all of these proposals are unlikely to be adequate anyway. It is a category mistake to expect assorted detritus from the active carbon cycle – even American shit – to ever match up to the CO_2 from fossil fuels. It would be gigatonne *and* bust.

Biochar reduces albedo – *dark* earths – and, never more than halfway from the surface, eventually leaks carbon. The leakage will accelerate as soils heat up. The efficacy of biochar as a climate cure is heavily dependent on the kind of soil it is applied to, and it shares the problem of sink saturation with standing forests.[122] Small doses could be terrific. Overdoses for treating the underlying depression would probably not be wholesome.

Diving while blindfolded

What could go wrong in the sea? The startups in this ‘space’ are quite literally jumping into it with their eyes wide shut. For they do not know what they are doing. No one does: no one knows whether marine removal will work, how it will affect the oceans, if it will do more good than harm or more harm than good.[123] One might then expect society to look closer, learn more, commission studies, set up laboratories, wait for robust evidence before diving in. But ‘there’s a counterpoint to the precautionary principle and that’s the duty to intervene,’ said Odlin of Running Tide: the urgency of the climate situation as a reason to run ahead.[124] ‘The way you get started is by doing,’ offered the chair of another startup.[125] Last but perhaps not least, there is a business case for impetuousness. ‘We need a business model that works now-ish or as soon as possible,’ explained Crumley of Pull to Refresh.[126] If you set up a private company to make money from marine removal, you do not want to hold your horses until the peer-reviewed literature has matured: you want to sell your credits now-ish, even if the contracted delivery will happen only in some future, as in any futures trading. The peer-reviewed literature was sufficiently quick on the draw to notice that

> the race to sink seaweed into the ocean is outpacing the rate of progress of the essential science to assess risks, surging past even perfunctory evaluation of the environmental impacts and social benefits. This lack of scientific evidence … has not prevented the private sector from currently offering carbon removal from sinking seaweed as an attractive marketable product where millions of $USD have already been invested.[127]

Some people are in a position to take liberties. Their startups might not live much longer than a weed bobbing on the waves, nor is there any mechanism to hold them responsible for failure or worse. As of this writing, in the mid-2020s, enterprising men have had a field day on the oceans and elsewhere, left to try out their technologies with minimal if any oversight or regulation: the dominant model for relating to non-human nature, from San Francisco to Tel Aviv. They followed in the footsteps of other enterprising men in the late 1990s and early 2000s, who had done exactly the same.[128] The broader mentality is recognisable from tulip manias and gold rushes and Ponzi schemes. In this vein, one actor calling itself the Climate Foundation started selling a ‘unique, serialised digital Kelp Coin™ security

token comprising a forward contract on a tonne of seaweed'. It cost just $250 and

> can be bought and held to maturity, after which we anticipate it can be exchanged on open markets and can serve as a store of carbon, a tonne of natural capital grown on a marine permaculture that regenerates life in the oceans. Finally when Kelp Coin™ security tokens are sunk anytime after maturity, we will causes [*sic*] a tonne of seaweed representing a tonne of carbon dioxide to be sequestered back to the middle and deep sea from whence it came.[129]

What, indeed, could possibly go wrong?

To start with the seaweed, it gained traction as a removal tech because of the worsening reputation of tree planting in general and BECCS in particular: it would consume no land.[130] But it would have to cover immense patches of ocean. To get just one gigatonne down per year, the seaweed farms would – according to the best current estimates in the peer-reviewed literature – have to carpet roughly 1 million square kilometres of open sea, more than twice the size of California.[131] That would only go for the most biologically productive littoral waters, however. On the high seas, poor in nutrients, the farms would need 24 million square kilometres to swallow one gigatonne.[132] What, then, would it take to remove the CO_2 from just one year of ongoing emissions? In the improbable best-case scenario, with productivity as high as in coastal upwelling areas, more than twice the size of Russia, or nearly half the Atlantic Ocean.[133] In the worst-case high sea scenario, about six times the size of the Pacific Ocean, or nearly twice the earth as a whole.[134] 'With a small amount of open ocean, we can get back to preindustrial levels,' said the skateboard dude; probably it would demand a whole galaxy of blue planets.

Any serious upscaling would take the kelp farms away from the shorelines, into rough weather, shipping routes, fishing waters and other challenges.[135] Before that, a familiar dilemma would arise: whether to put the seaweed into stomachs or seafloors. There is already an established industry for cultivating kelp, almost all of it in Asia, mostly in the waters of China. The algae are dried and sold on food markets.[136] Far beyond the Taiwan Strait and the Yellow Sea, this has come to be seen as an ingredient in the future of food. Because of the flagging capacity of the land to feed humanity, plus the emptying of wild fishing stocks, aquaculture has been given pride of place in the cookshops of the future; by the early 2020s, this

was by far the fastest growing sector of food production, seaweed at the top, curves pointing upwards.[137] Two or three decades hence, if the planet stays cramped, the demand for seaweed as a food source may well be several times higher. Some of it will be needed to feed fish in aquaculture ponds, some as organic fertiliser.[138] More people will want to use more of it for more purposes: and removal would enter this tug-of-war. Any serious upscaling could only come about by reserving the seaweed for sinking rather than eating.[139] Then picture the hungry crowds congregating in ports to watch unmanned vessels filling up with a source of sustenance and ferrying it to the dumping sites … Imagine the appeal of piracy, or sabotage …[140] There would have to be the aquatic version of bionecropower for this to work.

Kelp farms are monocultures in brown: how would oceans react to being wrapped up in them? We are here talking about an 'ecological invasion', an 'occupation of offshore waters with rafts of coastally derived macroalgae'.[141] There would be less underwater light, for a start. A shade would extend over marine organisms.[142] But needless to say, they do need radiation from the sun to live well. Over them would now come floating these buoys with kelp and a host of passenger species: fungi, viruses, bacteria holding onto the platforms and drifting up like microbial conquistadors. No one knows how the 'native communities' would survive their arrival.[143] Some local species might be attracted to the structures as to 'gigantic new sushi bars', binging on the dishes served; others could be crowded out of the canteens altogether.[144] No one knows how existing food webs might be thrown off balance this way or that.[145] Organisms such as phytoplankton grow – capture carbon, that is – by using nutrients suspended in the water, notably nitrate and phosphate; their limited supplies constrain the biological pump, which already operates at maximum capacity. Seaweed would have to break into this inventory. It would snatch nutrients from the mouths of plankton.[146] No one knows exactly what the effect on carbon fixation would be, but the suspicion has grown that seaweeds would squeeze out as much as it would simulate *or more* – releasing rather than removing CO_2 by forcing the indigenous pump to scale back.[147] 'Purposeful biological invasions have seldom been marine ecological successes,' one team cautions.[148] Not even the seascape is a desert waiting

for entrepreneurial men to make it bloom: that colonial imaginary has never been kind to nature, and it is unlikely to be so here.[149]

It is even doubtful whether any carbon would be sequestered at all. The whole sinking business is a bit of a lottery. In theory, letting the full-grown kelp fall off its scaffolds and drip down the water column will take its carbon out of circulation. But before that point, some of the biomass will secede prematurely – particularly if the farms are battered by strong winds and waves – and sail away into shallow oblivion.[150] Whatever does sink may not go far. Some will stop midway to the bottom and swim back up; a fraction will go all the way, but it is unclear for how long it will stay. Seas are not all created in the image of the same model. The Sargasso and the Southern Ocean will have different trip durations and storage rates and retention times; guesstimates suggest that on average, seven tenths of the carbon that makes it into the seabed will return to the surface within half a century.[151] But it could also be nine tenths in less time.[152] This is obviously nothing like the permanence of carbon in the atmosphere.

But then some observations of seaweed ecosystems suggest that they themselves *add* CO_2 rather than subtract it, because of the organic matter they absorb and secrete into the water.[153] They tend to give off halocarbons, a family of highly potent greenhouse gases (and ozone destroyers). The fraction they dispatch into the sediments might stimulate methane production; if this fraction is large – if biomass actually does rain down – microbes will gorge on it and resend the carbon as methane (depriving the bottoms of oxygen).[154] Any mass graves of organic matter, including cyanobacteria killed or trees drowned, would risk inducing the same methane rebound.[155] No one knows how bad it might be, and perhaps no one will ever know, because it is very difficult to monitor and measure these fluxes of carbon – trees grow in the gardens of humans, but whatever is planted in the ocean disappears into the closest there is to terra incognita.[156]

Albedo is a simpler matter. Blue waters will turn brown. Imagine half the Atlantic Ocean enveloped in seaweed meadows, for just one gigatonne: the effect might easily invert any cooling.[157] And it turns out that kelp is as sensitive to warming as any other living thing. The species grown in Chinese waters have their own nodal lines, beyond which marine heatwaves make them shrivel and rot.[158] Advancing armies of sea urchins that flourish in warmer waters have already devoured most of the wild kelp forests off

the coast of California. Along the shores of Tasmania, these landmark ecosystems shrank by some 95 per cent in the late 2010s.[159] From every angle, the 'outlook for massive scale-up of seaweed climate benefits is decidedly murky', on the best current science – not to say that it all seems like another folly.[160] Yet capital has already been committed to this 'marine real estate'.[161] How could it become one of the next hypes after BECCS? The explanation must be that powerful forces are pressing in this direction.

Other 'blue carbon' ideas seem scarcely wiser. If humanity could somehow stick 7 million Lovelock-like straws into the seas and use them to suck up water to the surface, it might remove just short of one gigatonne per year.[162] But this is not a certainty. No one knows, again, what would happen to the carbon upon ingestion by planktons; it might well bubble out ere long. Artificial upwelling would raise deep waters rich not only in nutrients but also in carbon, suddenly making contact with the air.[163] Blowing up cold water to the surface may well cause mass mortality events – after having tried to adapt to the general warming, fish and sharks could die from the freezing blast – and throw the distribution of heat, salinity, acidity and other variables into confusion.[164] Whales are nice. May they be restored in their glorious multitudes. But it would probably take a whole cosmos of them to clear out the carbon from fossil fuels. Sober scientific assessment has clarified that the contribution from them and their poo would be negligible, if they had any effect at all.[165] As for mangroves, seagrasses, saltmarshes and other attractive blue carbon redoubts of the world, estimates of their total potential have varied wildly, between 0.06 and 2 gigatonnes; it seems safe to say that the former would be harmless and the latter chancy.[166] Inflating these ecosystems would risk setting off methane bubbles. They are all, as we know, among the expected casualties of climate change itself (as are whales).[167] Not even an orgy of oysters would be as easy-breezy as it sounds: it turns out that calcification is a process releasing CO_2 to the atmosphere and oyster reefs a source of the gas. Proponents of this method stood accused of 'a fundamental misunderstanding' of basic ocean chemistry.[168] So much for fine dining our way out of overshoot.

Stuffing the accumulated CO_2 into the oceans seems, we may conclude, ill-advised. Science could not endorse it. This was the reason why oceanographers at scientific conferences were turning their noses up at the mention of Running Tide and spoke badly about them behind their backs.[169]

‘The methods used by Running Tide do not sequester any carbon dioxide from the atmosphere. Zero,’ one irritated expert ventured in public. ‘This company is a good example of the problems with carbon sequestration and why startups can’t be trusted,’ said another.[170] But perhaps the most remarkable thing was that all this followed shortly after a first bubble had burst. There was an early lesson available. It concerned the ocean iron fertilisation thought up by John Martin, and it mapped almost perfectly onto what was transpiring in the early third decade.

That sinking feeling

No sooner had the Iron Man made his debut than colleagues began to push back. An appendix of caveats unfolded: iron fertilisation would have insignificant effects; it would be impracticable; any gains would be transitory and lost as soon as the operation was paused.[171] In 1991, the year after Martin’s media sensation, a conclave of leading American experts in the field deliberated for three days on the merits of his proposition.[172] The ‘consensus statement’ summarising the discussions acknowledged the basic validity of the iron hypothesis and accepted that up to one quarter of ‘the buildup of CO_2 in the atmosphere’ could be neutralised by artificial fertilisation – if it was ‘continued for the next 100 years’.[173] But asterisks pointed to toxic algae blooms, jumbled species assemblages, scrambled nutrient distributions, dead zones in the deep seas following the putrefaction of organic matter and a range of other side effects. It was concluded that ‘massive iron fertilisation of the Southern Ocean to mitigate greenhouse warming is unwarranted; the potential gains are small relative to unknown, perhaps large, risks’ – hence governments ought not to consider this ‘a policy option that significantly changes the need to reduce emissions of carbon dioxide’.[174] The world had received advance warning about oceans as a safety valve for the excess.

But field experiments were encouraged as a way to find out more. In 1993, a team captained by Martin set out on a vessel called the ‘RV Columbus Iselin’, named after the former president of the Rochester and Pittsburgh Coal and Iron Company. It headed straight for a patch of tropical ocean south of the Galapagos Islands and distributed its iron payload. He

would not live to see it, but the results confirmed the first postulates of Martin's theory.[175] More experiments soon followed; all in all, thirteen between 1993 and 2009.[176] They conclusively showed that sprinkling the seas with iron did lead to local plankton blooms. But on the question that really mattered – what happens afterwards? – they were uniformly disappointing. Of the thirteen experiments, two showed some export of carbon into the midnight zone. The rest found little to none. The efficiency of artificial iron fertilisation proved to be on average ten to twenty times lower than from similar natural episodes, which, in turn, were fifteen to fifty times less efficient than Martin had first hypothesised.[177] The lion's share of the carbon fixated in the initial blooms was lost in the mazes under the surface long before it reached the darkness. Who would have guessed?

Not even computer models could represent more than an ideal one gigatonne per year, on the condition that the entirety of the Southern Ocean – some 16 per cent of all sea surface – be fertilised with iron for the duration of a century.[178] 'You give me half a tanker full of iron, I'll give you another Ice Age' turned out to be hyperbole, also because the amount of iron would have to be several orders of magnitude larger than Martin had thought.[179] Perhaps most importantly, the original concerns about cascading side effects from the symposium of 1991 were reinforced throughout these decades of intense research.[180] Twenty years on from his quip, the verdict was unequivocal: all this research, one review concluded, had produced no support for 'the idea that ocean fertilisation would provide a particularly effective approach to counteract the increasing atmospheric levels of CO_2, even within a wider portfolio of measures'.[181] Another review offered an obituary. 'Perhaps it is time to break the two-decade cycle of debate and accept that we know enough about ocean fertilisation to say that it should not be considered further.'[182]

And yet all this time, a succession of startups headed by zealous white men sprouted forth from the US West Coast. In total disregard of the scientific scepticism, they laboured away to make iron fertilisation a reality; some consolidated a carbon offset business around it. Already in the 1990s, there were GreenSea Ventures and Carboncorp US, soon followed by Ocean Carbon Sciences, Climos, Planktos, Oceaneos.[183] These aspiring pioneers seemed to float around in their own little mental and monetary bubbles. One

oceanographer recollected a meeting in 2007 in which some of them were in attendance:

> It's amazing how long it took to kill the idea … I felt like all these people at [that] meeting were like slot machines, I could just see the dollar signs rolling in their eyes, and they just weren't really thinking of or aware of all this work and science that had been done to basically show that iron fertilisation was not a good idea.[184]

What did kill it, in the end, was one of their own. Russ George, the founder of Planktos, in 2012 rose to infamy when, in defiance of standing rules and regulations, he dumped 120 tonnes of iron sludge off the coast of Haida Gwaii in Canada to 'replenish and restore' the 'ocean pasture'. The entire environmental movement was up in arms.[185] George soiled the source that was to give his industry the gift of life; deeply tarnished, iron fertilisation went on an extended hiatus.

Just a few years later, however, the quest continued with seaweed, and upwelling, and whale poo. All put new wine in Martin's old bottle and reproduced variations of its problems: scant if any scalability, possible uselessness, potentially shattering blows to the ecological communities under the surface.[186] And yet the startups just kept coming. This was not the first nor the last time the search for negative emissions technologies moved in circles. Out in the 'ocean space', those circles linked up with centuries of bourgeois mistreatment: since the dawn of capital, the sea has been perceived as 'a favoured depository' for stuff the terrestrial world 'wishes to discard and conceal', a 'forgotten space', out of sight, out of mind.[187] Here could be dumped everything from the corpses of slaves to illicit fortunes. Penal colonies and toxic waste, avoided taxes and laundered money – 'the offshore world covers a multitude of sins'.[188] In *Capitalism and the Sea: The Maritime Factor in the Making of the Modern World*, Liam Campling and Alejandro Colás have tracked the long waves of such 'offshoring'. The practice flows from the fantasy of the sea as a zone of lawlessness and free experimentation. Something about it – the vastness, the remoteness; the tendency of things to disappear under the waves; the solvency of the water – seems to exercise an enduring attraction on a bourgeois subject in need of throwing its shit overboard.[189] But the sins have had a way of washing ashore. Ocean-based removal is but another page in this log book.[190] We should expect more entries to follow, for it does not seem to matter how

much we know about the tendency of things submerged under the waves to return to the surface. What matters is the steadily rising pressure to dump the accumulating waste of capitalist modernity somewhere, anywhere.

Weathering vicissitudes

For enhanced weathering to make a measurable impact on climate, it needs land. Removing two gigatonnes per year might require 20 million square kilometres of tropical fields and forests on which to distribute the crushed stone, more than twice the area of Brazil.[191] A startup like InPlanet would have a lot of work to do. There is a major difference, however, between enhanced weathering and technologies directly attached to photosynthesis, in that the former does not need any land – or water, or nutrients – of its own: it will not have to elbow out food production.[192] Adding rock dust to the soils could just make them healthier. It would stabilise them, counter erosion and acidity, replenish various nutrient supplies.[193] One would not have to carve out new single-purpose estates, but could make existing soybean and sugarcane and palm oil plantations double as sponge surfaces, for their own benefit.[194] It would just have to be a continental-scale giga-deployment of technology. Perhaps the spreading could be most economically executed by 'helicopters or fixed-wing aircraft equipped with agricultural spreaders that are used to spread basalt in the form of free-flowing dust or slurry' or by 'large aerial tankers such as those currently used for firefighting'.[195] Imagine the fleets of helicopters or water bombers circling over the tropics to spray them in dust. Like DDT, but manna this time.

Or might there be undesirable consequences here too? Inhaling pulverised basalt is not ideal for the body; it could increase cancer incidence, making delivery from above seem particularly unsound.[196] On closer inspection, throwing out this grit over the soils may perturb their prevailing chemistries in any number of labyrinthine ways.[197] Everything would depend on context: on certain soils, fertility might drop, or weathering become inhibited.[198] This is one reason why Brazil was such a popular destination for startups in this segment of the space: weathering works better in warm and wet climates than in cold and dry ones. Soils need

be acidic enough to help dissolve the dust and release its minerals, and to prevent the carbon from escaping; and once again, it so happened that the prime lands were located in the old colonial peripheries.[199] But even there, the purposes might not align. Optimising removal could mean dumping ten to twenty tonnes of dust on every hectare, but most soils would ask for no more than three to five for their own health.[200] No one knows how living organisms would react to having a mountain chain of rock ground over their heads.[201] This is not because silicates are alien to the environments but because of the quantities involved: similar question marks would arise if a planetary-sized bucket of tomato juice was emptied over the tropics. Imagine then, again, the helicopters starting to hover over fruit farms in Jamaica or tea plantations on Java … Imagine extracting consent from farmers on the ground, not to mention setting up the regulatory system for monitoring consequences and removal rates across soil types and rock elements and delivery methods and other features of the operation. This would be bionecropower too. While it would not have to evict people or lock them out of food stores, enhanced weathering would infiltrate land already in use, so as to make more carbon drop dead in sediments. Power over people would have to be in place for the technology to reach meaningful scale.

And where on Earth will all the stone come from? The silicates already lying around in the slag heaps of mines and factories would be an innocuous source; but there is the usual scale problem.[202] Enhanced weathering for more than one gigatonne would have to be backed up with a new monotonous mining industry.[203] It might need to extract as much material as the entire cement industry in the world today and grow as fast as that industry did in China in the first decade of the century.[204] It would be another worldwide extractivist enterprise stomped out of the ground – a blessing for some: ‘a new market for the mining industry currently suffering overcapacity’.[205] But it would hardly be a blessing for people and nature. The quarries and grinding machines would very much demand territory of their own – preferably inside the tropics, if that is the destination of the dust – and so one can expect fresh wounds on already lacerated lands.[206]

Unless, that is, material could be cajoled out of nature in innovative ways. The glaciers of Greenland have been grinding rock forever. Each year they produce about 1 billion tonnes of ‘rock flour, which flows as mud from

under the glaciers' – 'essentially unlimited' quantities, extraction from which 'would have very little effect on the local environment'.[207] One would just have to ship the flour from Greenland to Jamaica and Java … another maritime industry is born. According to the scientists behind the idea, 'the whole Earth's agricultural areas could be covered with this, if you wished.'[208] Possibly, but if a capitalist industry is charged with gathering the goods from Greenland, it will not pick a few stones here and there like someone strolling on a beach. It will look for the most concentrated deposits, perhaps a gravel mountain under a particularly abrasive glacier, and then move in the heavy machinery to dig it all up until nothing but a hole remains. Then it will move to the next site. This is how actually existing extractivism works – not by lovingly combing the hair of mother nature but by maximising output from every discovered orifice. Enhanced weathering will not be any different, unless the mode of production is.

Because the oceans are the end station for the carbonates from the weathering, typical uncertainties apply: what happens on the way there, as they seep out of soils and into brooks and rivers and deltas and finally out into the open sea? Some carbon might instead linger on site and refuse to leave; at least a portion will be lost to the atmosphere.[209] And what happens inside the sea upon discharge? It will be good for calcifying organisms. They will be super-stimulated, so much so that 'the blue ocean could turn into the "white(r)" ocean'.[210] Picture seas filled with foraminifera. Or mussels and oysters everywhere; good for some menus. Ocean alkalinity enhancement has all the same problems: another mining industry, food chains off kilter, varying degrees of leakage, expected gains that might turn into further losses of carbon.[211] And if it works, there will be outgassing.[212] Nature is not a god of mercy. In the early 2020s, the science of the effects of fossil fuel combustion was overripe, but that of many negative emissions technologies was still in its infancy. The former could tell us everything needed about what to avoid, the latter very little of positive certainty about the antidotes on sale.[213]

Chasing the wind

The whims of nature, however, can be largely sidestepped by DAC: this machine needs no land to work for it, nor any sea. It makes no claim on biologically productive space, because it has disassociated from photosynthesis by emulating it. All it needs is a surface for contacting air. This can be found on the rooftop of a factory, on a train, inside rooms, wherever humans spend their days. Estimates of the ratio of land demanded by DAC relative to that by BECCS vary between 1:400 and 1:2400 per unit of captured CO_2; compared to every alternative, the former is an angel floating above the ground.[214] When Climeworks claimed to do the job of 36,000 trees with the footprint of one, this was not mere bluster.[215] No food supplies need to be ransacked, no wildlife assaulted. Water consumption is only slightly less impressive in its frugality: an estimated ratio of 1:143 as against BECCS.[216] No irrigation is needed; nothing needs to be fertilised. There is no albedo problem.[217] Every DAC module could be shrouded in the colour white if one so wished. Because this technology does not seek to augment any pre-existing sink – because of its estrangement from trees and waves – disturbances such as fires or sea urchins are of no account; the impacts of climate change can pass through DAC like arrows through a phantom.[218] Some might take less of a fancy to DAC than to natural climate solutions and other items in the catalogue, on the premise that what is closer to nature is also better for it, but an appraisal free from hippie prejudice would suggest the opposite: it is precisely by detaching as far as possible from ecosystems that DAC avoids putting even more pressure on them and itself avoids the pressure from climate breakdown. Sometimes alienation from nature is best for nature and people alike.[219]

Instead, DAC is all about another phenomenon: energy. As lightly as it treads on other resources, it is heavy-footed here. We have seen that there can be no levitation above the thermodynamic gravities of ambient air capture. For DAC to jump scale, a colossal quantity of energy would have to be dedicated to it: in one seminal – and by no means pessimistic – assessment, the technology could sprint to an annual capacity of 30 gigatonnes, reaching a cumulative total of nearly 500 during this century.[220] That would require the building of roughly 1 million facilities as large as Mammoth, one of its kind as of 2024.[221] Were this to transpire, come year 2100, DAC would use electricity equal to more than half of all that was produced in the late 2010s, plus heat equal to more than half of all final

energy consumption.[222] Raise the ambition a little and you would have to construct one full duplicate of the global energy economy, just for sweeping CO_2 out of the air. But that counts only the energy for running the DAC plants, not for manufacturing them; add that and you have to augment total demand by another third, in the best case.[223] As ever, these are inexact figures. But there can be little doubt that DAC at scale would be an energy behemoth.[224]

In this respect, it compares poorly with the contenders: none evinces the same intake of energy.[225] Friends of BECCS like to point out that it does not withdraw but generates power.[226] This should be taken with a pinch of salt, because some of the bioenergy in a plant must be used for scrubbing and compressing the CO_2, the CCS component a parasite on the BE; further energy is lost along the chain when biomass is harvested and processed and transported. At the end of the day, BECCS may not produce electricity exceeding the energy it wastes. Compared to solar and wind, it is abysmally inefficient, worthless even; an economy could endanger its 'energy security' by relying on it.[227] But DAC is a greater drain still. Seaweed would float with the waves. Wolves and whales have their own means of locomotion. Artificial upwelling and iron fertilisation would require machines that consume energy, as would enhanced weathering, for mining and grounding and spreading stone.[228] But DAC is worse. Even Direct Ocean Capture might beat it, because it takes less of an effort to smoke out CO_2 from the sea.[229] Indeed, lamps over the rainforest would supposedly be less consumptive, even accounting for the manufacturing of all the cables and bulbs (although most energy from the lamps would end up 'as heat, which increases local temperature'.[230]) DAC stands unrivalled in its energy extravaganza.

Such voracity creates real headaches for the startups. Without the requisite juice, even the boldest, most well endowed among them remain impotent. In late 2024, CarbonCapture announced it was abandoning its plans for the 5-megatonne Bison project in Wyoming because it was 'unable to secure enough carbon emissions-free energy'. That energy had been gobbled up by 'industries that are emerging much faster than anybody would have ever predicted,' notably those enlightened stars of socially necessary energy use: AI and 'cryptocurrency miners'.[231] Climeworks was caught in the same general trends: 'the energy challenge is massive for us',

it was forced to acknowledge when starting to plan its first US projects in 2024.[232] That challenge can only have grown when Donald Trump then ripped up the entire support infrastructure for renewables in that country.

Its hunger for power also gave DAC an image of expensiveness.[233] On the general view, cost needs to go down to $100 per captured tonne of CO_2 for any gigatonne deployment to be affordable.[234] Early in the days of DAC, the disheartening price tag of $1,000 – ten times the acceptable level – circulated as a more realistic estimate.[235] Climeworks reported $600–800 for its earliest models, but then costs actually went over $1,000 when it started operating in Iceland.[236] Carbon Engineering publicly reported a span of $100 to $230 and Global Thermostat boasted of $100, although a more accurate estimate of whatever was going on inside that company probably hovered around $600.[237] Neither had full plants in operation, and one of the lessons from Climeworks was to not rely on numbers from pilot plants, before the full challenges of engineering are known.[238] Transparency is never complete in these matters.[239]

What are the prospects for slashing costs in the decades ahead? High hopes have been pinned on AI cheapening every step of the supply chain (and discovering the ultimate sorbents).[240] Optimists would also point to solar panels: much like them, DAC devices can shed their costs at the economic speed of light, when they begin to be mass produced on assembly lines. Manufacturers will learn to cut corners and streamline processes, particularly if the units are kept small like Lego bricks; this will allow for more entrants into the field to experiment.[241] There is no similar potential for trimming the socially necessary labour time of, for instance, BECCS. The exchange-value of that technology will rather tend to rise, as land becomes scarcer and of poorer quality.[242] So how low could DAC go? Never the shy bachelor, Lackner thought that the price could drop all the way to $30 per tonne.[243] Spiritus, the startup with the squishy white balls that looked like relief toys, claimed to have a schedule for undercutting $70.[244] Pessimists would call these pie-in-the-sky figures, point to the commonly omitted expenses for compressing and transporting and storing the CO_2 and suggest that the industry will never reach $100; we could rather slide back towards the decuple.[245] A more relevant analogue than solar power might be nuclear, which, after nearly a century of technological

perfection, remains as expensive as ever.[246] No one really knows which way DAC would go. This is a future to be made inside the black box of engineering.

Some parameters are discernible, however: the cost of electricity and heat will remain determinant.[247] We have seen how the early starters worked to innovate their way out of the thermodynamic curses – Lackner relying on the wind to propel air; or, super-slick startup Verdox producing sorbents that would give up their catch when zapped with an electrical current, thus eliminating the need to heat them up. Verdox claimed to do away with seven tenths of energy demand.[248] We are not in a position to rule out such miracles. But not even the cleanest of ovens come for free, and even Lackner acknowledged that energy consumption cannot go below a certain floor.[249] Climeworks was smart to pick cheap waste heat in Zürich and cheap geothermal heat in Iceland, but as with other removal techniques, scale might force actors to burn through easy pickings and select dearer supplies, with the result that costs plateau.[250] The value of raw materials will not necessarily decline. Labour could go any which way.[251]

But then there are, of course, also strictly political considerations: a mighty state apparatus could decide that it will rise to the occasion and pay *any* price. It could take the budget of its military defence and give it to DAC instead, or slap any amount of taxes on capital, or print money. Cost, in the last instance, is a matter of social priority. Christian Parenti, a DAC aficionado on the left, ventured the total figure of $12 trillion for removing 40 gigatonnes – three times the current GDP of Germany – every year; yet another educated guess. It could be less, it could be more, but another scenario is 'always more expensive': 'That is permanent global economic collapse caused by rapidly rising seas, flooded coast cities, desertification of the globe's key grain-exporting breadbaskets, colossal settlement-ravaging wildfires, proliferating disease, and attendant social breakdown.'[252] Weighed against the sum of the avalanches, any price for DAC might appear a bargain.

But with all priorities come hard choices on the ground: should energy be rerouted to DAC? It goes without saying that the energy fuelling this machinery ought to be renewable. Burning fossil fuels for capturing CO_2 from the air – like Global Thermostat in Colorado – would be like chasing one's own tail.[253] Plenty of studies do assume that gas will supply the heat,

but this is not sensible.[254] The heat should come from solar collectors or geothermal seams or some other non-fossil source, or one might as well desist.[255] The only reasonable vision is of a 100 per cent flow economy that allocates some of all that flow to DAC; and given its lack of exchange-value – in other words, the tendency for the price of solar and wind to fall towards zero – this could make the technology cheaper than imagined.[256] In the best of possible worlds, provided the caveats appended to such scenario can be avoided, it might inaugurate an era of energy cornucopia. *On the way there*, however, supplies of the flow will be constricted. If a transition away from fossil fuels ever commences, solar and wind will be needed to replace them in every sphere of the economy. *During the transitional period*, each gigawatt of renewable energy devoted to DAC is one gigawatt unavailable for displacing fossil fuels, each dollar spent on the former lost to the switch. On these grounds, Mark Jacobson, the leading scholar of a 100 per cent flow economy, has laid down a stiff law: before fossil fuels are fully phased out, it is always preferable to use one watt or one dollar for direct substitution from solar and wind; nothing should be spent on DAC, until the time comes when the accumulation of CO_2 is a memory.[257] Removal makes little sense before addition has ceased. Slowing down the cessation by siphoning away resources makes none at all. There is a compelling logic to this law.

We can here see the outlines of another modality of power, which, using Dominic Boyer's twist on Foucault, can be called *energopower*.[258] Insofar as the diffusion of DAC runs in parallel with a transition, power will have to be exercised over people through the distribution of energy. Will electricity and heat from wind and solar be used for hospitals and refrigerators and air conditioners and tofu factories or for DAC facilities (or worse still – AI data centres and cryptocurrency 'mines')? If any cornucopia can materialise on the other side of the transition, the journey there – particularly if undertaken under rising temperatures – is bound to include crunches and selections; and because energy is an input in the fulfilment of basic needs, this entails that people are arranged in relations of power.[259]

But there might be a silver lining that relaxes this imperative. The flow is known for its tendency to overspill. Grids that run to some extent – it can be far less than 100 per cent – on solar and wind are periodically inundated by a surfeit of electricity: days when there is no cloud in sight, or the wind is

fierce, or both. Perversely, this makes the flow off-putting to capital, because in those moments there will be so much electricity on the market that all value and profit vaporise.[260] The best use of this excess, of course, is to try and store it, saving the sun for a clouded day. But after the batteries have been filled, why not let DAC lick up the rest? One does not by physical necessity have to run the units around the clock. Especially if they are of the decentralised, backyard Lego variety, they can be on standby for very sunny and very windy days, switched on and ramped up to maximum capacity at a moment's notice.[261] (On some accounts, Direct Ocean Capture would be even better suited for this.)[262] This customer would not have to make claims on baseload electricity – it would, so to speak, be let into the pub only when the bartender has too much drink on her hands. Treated in this manner, DAC would not have to be exiled to a future when the transition is completed, but can be invited here and now to the regions where redundancies are within reach – those most blessed with solar and wind: countries in the Sahara, the Iberian Peninsula, Scandinavia.[263] Spread like crystals over the sunniest and windiest parts of the earth, DAC devices could begin to pull out CO_2 even as the flow advances and ousts the stock across all terrains. Removal could begin now and be ratcheted up over time: stop-and-reverse as a combined transitional programme. This might be the most concrete utopia on offer in the catalogue.[264] There are, however, as we shall see, major hurdles standing in its way. Already now we can easily spot yet another version of the scale problem. Holding DAC capacity dormant until days of surplus electricity makes little sense if the quantities to be captured are truly enormous.

But DAC does not live on energy alone: there will have to be sorbents in droves, steel by the ton, concrete for the foundations (not to mention the materials for the wind turbines and solar panels into which DAC will be plugged).[265] One business-minded think-tank has eagerly anticipated a doubling of steel demand in the US by 2050.[266] Where would all the sorbents come from? Some are currently made with feedstock from fossil fuels; others are derived from renewable materials; none involve rare elements, but much of the minutiae is kept in the dark from science and society, as the startups jealously guard the secrets of their liquors. It goes without saying, again, that this whole supply chain must be transferred to a non-fossil footing, or a scale-up might defeat itself. The transition would

have to make its way through every moment – production of sorbents, steel, concrete; transportation of components and finished product.[267] (The same applies to every other tech we have inspected: the ships ferrying biomass, the boats driving seaweed or iron, the heavy-duty trucks carrying rock.)[268] On the other side, there will be trash. When they can no longer be recycled, heaps of chemical sieves might be left lying around. Sodium hydroxide – the choice of Claire Lackner and Carbon Engineering – is manufactured through a process that also generates chlorine gas, known as a chemical weapon from the killing fields of Ypres and Aleppo. One million DAC facilities and we are potentially looking at a disposal problem.[269]

And one million might be rather a low limit. Outgassing needs to be factored in. Lackner has sketched the equation: 'If a drawdown of CO_2 becomes necessary', humanity should use DAC to cut the atmospheric concentration by 100 ppm – say, from 500 to 400 (this would not in itself be particularly ambitious, given the dangers lurking above 350 or so). But half of all the captured CO_2 would be back in the atmosphere after the reflux from ocean and land. If it would take 750 gigatonnes to revert to 400 ppm, it would take *as much again* to beat back the outgassing and stay in place. Summa summarum: 'This would require the construction of 300 million DAC farms' – not one, not two, but *300 million* facilities the size of Hinwil.[270] Clearly no one knows quite where this might end. But it seems that the earth might have to be wreathed in a metal crown for mass DAC to do its duty. Even if one builds facilities that capture hundreds of times more than Hinwil, it is not immediately apparent that the world has vacant lots crying out to be covered with such units – the tech could be caught in the constraints of land not for cultivation but for construction – nor can one assume that supplies of water and materials and waste disposal systems can be easily stretched infinitely.[271] Whichever way you turn it, the burden of overaccumulation will be a heavy one to carry.

A haunted afterlife

DAC and BECCS have one thing in common: the terminal station for the carbon is under the ground. (DAC might be the catchiest acronym in the

catalogue, but it is sometimes written DACCS, for Direct Air Carbon Capture and Storage, emphasising its resemblance to the ungainly sibling.) Both aim to compress the gas into a liquid and pour it into lithospheric bottles. This is, somewhat like DAC in submarines, an established technology: since the 1970s, American oil companies in particular have had a habit of injecting pressurised CO_2 into sedimentary formations, for purposes we shall soon examine.[272] It can be done, and the earth appears to be perforated with enough cavities to welcome home all of the emitted carbon dioxide and then some. Estimates for the amounts the available space could accommodate range from 8,000 to 35,000 gigatonnes.[273] Storage capacity as such does not appear to pose a limitation on DAC or BECCS – there is no shortage of holes that can hold their product.[274] But not all of them can be filled easily or at speed, an inconvenience commonly overlooked. This is one reason why some existing CCS projects have persistently failed to store the amount of CO_2 promised. Excess pressure in wells, unforeseen clogging, underground formations generally not behaving as desired – all sorts of issues have made injection more difficult than expected.[275] One study mapped these constraints imposed by geology and the rate of scale-up and saw the estimates dwindle to no more than 5 or 6 gigatonnes by 2050.[276] Such small amounts would leave plenty of emissions homeless, cutting off the most direct road to reversal. But even in those numbers, another problem soon presented itself. It concerned safety.

Carbon dioxide in concentrated form is, we recall from the deeds of Drebbel, poison. At the density and pressure we are concerned with here, it causes more than just dizziness and fatigue. Each year, some 100 workers around the world are killed by sudden exposure, often in restaurant basements where bar mixers are operated with pure CO_2; it is an established technology for euthanising lab rats.[277] The compressed gas lunges at its victim, choking it to death. Because deposits occur naturally in the crust, such killing does not have to be administered by humans. On the morning of 21 August 1986, the people in a village next to Lake Nyos in Cameroon woke up to the sound of rumbling and bubbling. One man saw a white cloud rising out of the water. He and other survivors described feeling warm, light-headed, short of breath, confused before losing consciousness. Within a few minutes, about 1,700 of their neighbours dropped dead – ‘“died in their tracks” without evidence of agonal struggle’, said the

autopsies – and no birds or insects or other animals were seen in the area for the next two days.[278] The source of the poisoning was concentrated CO_2 released from the waters of the volcanic lake. The scientific reconstruction could not identify the proximate cause of the discharge, but concluded that it could have been

> an internal wave, a seismic shock, a landslide or heavy flood of water into the lake, or nearly any disturbance of this metastable system … The gas release could have been triggered by any disturbance that vertically moved water a distance greater than the critical amplitude. As waters approach saturation with respect to CO_2, the critical amplitude approaches zero, and extremely small vertical water movements could trigger degassing.[279]

We recognise here the dialectics of disaster.

For carbon capture and storage to work on a mass scale, there has to be a system for moving CO_2 to sites of injection, and one form it can take is a network of pipelines.[280] American oil companies already have pipes in place, very similar to those for so-called natural gas, but filled with carbon dioxide. They too can rupture. On 22 February 2020 – when the world would have been rather more preoccupied by a spreading virus – residents of a town in Mississippi saw a dense, powdery cloud settling over their valley. Dazed and nauseated people gasped for air and collapsed in their chairs. 'Cars just shut off, since they need oxygen to burn fuel. Drivers scrambled out of their paralyzed vehicles but were so disoriented that they just wandered around in the dark.'[281] Nearly fifty were taken to hospital; luckily no one died in this first known incident of mass exposure to a bursting CO_2 pipeline. But the same thing happened again on 3 April 2024, when the same white cloud gushed out of a pipeline next to a town in Louisiana, ironically named Sulphur. It was the same network that had experienced the accident four years prior; since then, it had been acquired by ExxonMobil, which, as we shall soon see, had just developed a keen interest in DAC.[282] As of this writing, the US already has an average of four 'CO_2 pipeline incidents' every year.[283]

Still, such pipelines are few and far between even there. Gas and oil pipelines are all over the place, but repurposing them is not advisable. Pressurised CO_2 is highly corrosive and will eat through the steel commonly used; special fortified steel is required to hold this liquid in

check.[284] A scheme for large-scale injection thus requires the multiplication of CO_2 pipelines, but who would like to live next to them? 'We're already living with PTSD from all the industrial plants. Now they want to add CCS,' sighed a community organiser in Sulphur.[285] Plans to build a 2,500-mile-long CO_2 pipeline across five states – the 'Midwest Carbon Express' – ran into fierce opposition from landowners of all political bents. It would collect CO_2 from a string of biorefineries and ethanol plants and deposit it for burial in the North Dakotan underground. In meetings attended by hundreds, speakers fired up the crowd to 'bog this thing down as hard as you can'.[286] This thing would be a fresh layer of infrastructure, which, even if designed to invert the outcomes of the older layers, would provoke new rounds of NIMBY-ism or place-based resistance or whatever one prefers to call the predictable reactions. There would be invocations of eminent domain, zoning issues, community consultations – or barricades cleared and protest camps raided and militants shot in the head – again demonstrating that aloofness from land is only relative.[287]

Some of the need for pipelines could be obviated by placing capture devices on top of the final resting places, as Climeworks had done in Iceland. Ambient air is everywhere, and so DAC can be too; it is this abstract space that gives the technology its charisma.[288] You can push down costs by combining it with any other structure, a waste incinerator in an industrial area or an auditorium on a university campus. But if you do, there will have to be pipelines to bring the CO_2 to the injection sites. If you wish to avoid building pipelines, DAC will instead have to be reinstated into concrete space and fettered to particular locations. Where would they be?

CO_2 can be repatriated to aquifers deep in the crust that hold saltwater unfit for use or to depleted oil and gas fields. There is a redemptive beauty to the latter vision: first there was carbon in those fields; then humans made the mistake of extracting it; now they will correct for it by pumping the element back where it belongs.[289] There is nothing definitionally impossible about this. In Norway and Algeria, oil and gas companies have been injecting liquid CO_2 into aquifers for decades; and then there is that one BECCS plant in Illinois, and a few minor pilot projects.[290] But good storage sites are not evenly distributed.[291] They must have some reassuring features – above all, a caprock that will not let anything slip out, a stone that

seals the cave without any chance for mishaps.[292] 'The injected CO_2 will remain as a separate fluid for a significant period of time, with a strong buoyant drive upward.'[293] Revenant of fossil capital, it will seek to escape from internment, but this must not be allowed. Not only can leaking CO_2 contaminate groundwater and suffocate masses of people and animals; it would, obviously, render the capture itself null and void. Leaks have been detected in both the Norwegian and Algerian formations.[294] Aquifers that otherwise appear suitable might sit close to fault lines. As for depleted oil and gas fields, their caprocks – once solid like the walls of a high security prison – will have been riddled with wellholes during extraction.[295] What, then, would it mean to pump hundreds or even thousands of gigatonnes into caves of this kind?

Volumes of such magnitude would build up pressure inside the crust. It is not infinitely commodious and plastic: contradictions between forces of order and forces of destruction might develop. 'Because of the critically stressed nature of the crust, fluid injection in deep wells can trigger earthquakes when the injection increases pore pressure in the vicinity of preexisting potentially active faults'; the brittle rocks in the interior would be 'subject to failure, often in response to very small increases in pore pressure'.[296] Bottled-up energy would then be released in quakes. Even small internal tremors can threaten the integrity of the seals above. Cracks in the walls would let the prisoner leap out. If enough carbon is captured from the air, self-organised criticality in the biosphere could be exchanged for the same in the lithosphere (with a potential to renew the former, if extensive enough). Instead of avalanches from above, there would be convulsions from below, hard to predict for reasons typical in the vicinity of nodal lines. Induced seismicity is already a common effect of fracking; but here, the forces locked up underground would be of another order.[297] There may be reasons for people living near designated storage sites to resist their fate. Spectral and unexpected, leaks of concentrated CO_2 have a way of catching their victims unawares.[298]

One way of removing this hazard would be to find locations so remote that no people live there. An ideal place could be Kerguelen, an underwater plateau in the southern Pacific Ocean, just north of Antarctica. 'Perceived as one of the world's last great wildernesses', this oceanic crust could house

a slew of CO_2, without any neighbours having to worry about leaks.[299] Impaling it with strings of wind turbines would provide electricity. Similar sweet spots for DAC hubs – combining abundance of renewables with out-of-the-way storage – could be found in Morocco, Argentina and, of course, Iceland. If such a map of concrete space were to be followed, someone would need to gather the world's DAC facilities into a handful of super-prime locations for the recovery of the planet as a whole. This would be expensive, good for people in cities, bad for wildlife in the sacrifice zones.[300]

Another, more durable form of hazard removal would be mineralisation: converting the CO_2 into carbonates inside rocks. If one could get the gas to turn into stone, leakage would not be a problem. Stones do not seep. The chemistry would be the same as in weathering: CO_2 dissolved in water reacting with rocks to form carbonates; hence the process is also referred to as 'managed carbonation' or 'mineral trapping'.[301] One might think of it as the immurement of CO_2. Rather than keeping the gas imprisoned in a cell with locks of varying degrees of safety, it would here be walled up, its buoyancy and mobility snuffed out as it becomes one with the stone. A suitable material – as in enhanced weathering – would be basalt, which covers some one tenth of continental surface area and most of the ocean floor. There is no shortage of this type of brick either. But would it not take many thousands of years for the CO_2 to meld with it, as in unassisted weathering? To test this discouraging hypothesis, CarbFix, an Icelandic startup, injected dissolved CO_2 into basaltic rocks at a depth of more than 400 metres east of Reykjavik. It was this company that later partnered with Climeworks at Orca and Mammoth, the Swiss capturing CO_2 from the air, the Icelanders shooting it down into the crust. Scientists associated with the project could not directly monitor the fate of the fluid; instead, they used a suite of chemical 'tracers'.[302] After 550 days, the trace of CO_2 had been lost. More than 95 per cent was missing in the samples. Where had it gone? 'The most plausible mechanism', said the paper later published in *Science*, 'is carbonate precipitation' – in other words, the CO_2 must have disappeared into the stone, within less than two years.[303] The findings were widely greeted as a revolutionary discovery that opened the door to mineralisation on timescales short enough to bend the climate curve.[304]

Here was proof of ‘permanent, solid storage’, ‘feasible and safe’.[305] Sixty million gigatonnes of CO_2 could be subjected to *in situ* mineralisation in this manner – truly a fantastic figure.[306] An editor at *Science* coined the slogan ‘Inject, baby, inject!’ to invert the infamous Trumpian chant ‘Drill, baby, drill!’[307]

But there was another team of scientists who also followed the experiment. Lead by the French microbiologist Rosalia Trias, they pointed to an overlooked fact: basaltic rocks teem with life. They are habitats for vibrant communities of bacteria, a deep subsurface extension of the biosphere. Many of these organisms eat CO_2 as food. How would they react to being treated to a splurge? Trias and her team found something more concrete than a mysterious disappearance: when the injection was at its most intense, bacterial biomass in the targeted depths grew by a factor of 500. CarbFix had instigated a bloom of marvellous proportions. Among the bacteria that suddenly reproduced in this orgiastic fashion was the genus *Desulfotomaculum*, commonly known in kitchens around the world from poorly preserved food in cans. The vanished CO_2 might not have become stone at all – rather, it would have sprung back to life in the form of legions of labile bacteria.[308] These results punctured the faith in mineralisation, because ‘the lifetime, the thermodynamic stability, and the mobility of a microbe have nothing in common with those of a mineral’.[309] How would the lithospheric biosphere respond to the injection of many, many gigatonnes? The ground under human feet could be foaming with life, much like a cellar into which all the dung from the nearby dairy farm is poured. DAC would end up dissolving in the pulsations of animate nature.

Neither Climeworks nor any other company in the DAC business or agent of negative emissions technologies spoke much of the Trias study, or indeed any other caveats around mineralisation. Cost is one. Mass injection into rocks would demand its own tidy sum of energy.[310] More damaging is the state of general uncertainty. As of this writing, no one knows what the ultimate fate of gigatonne upon gigatonne of CO_2 shoved into the ground would be.[311]

The double tragedy of overshoot

Four conclusions can be drawn from this appendix. First, let us not

> flatter ourselves overmuch on account of our human victories over nature. For each such victory nature takes its revenge on us. Each victory, it is true, in the first place brings about the results we expected, but in the second and third places it has quite different, unforeseen effects which only too often cancel out the first … In relation to nature, as to society, the present mode of production is predominantly concerned only about the immediate, the most tangible result; and then surprise is expressed that the more remote effects of actions directed to this end turn out to be quite different [and] are mostly quite the opposite in character,

as Engels wrote in *Dialectics of Nature*.[312] The appendix paints a picture of secondary and tertiary and quaternary effects of negative emissions technologies, going off like so many rockets in all directions. Exactly where and how they will strike is hard to gauge *ex ante*. But each has the potential to create another front of late climate politics, the side effects a formula for perpetual multiplication.

Second, the establishment of negative emissions technologies passes through power over people. As they are inserted into a planet in the throes of rapid warming, they have to lay claim to parts of a resource base that is already eroding. Getting them to work at scale will require amplified vectors of power, concerning basic conditions of life: what to eat, if anything; how to use land; where to dispatch electricity; whether to let a homestead be intersected by a pipeline. Bionecropower and energopower are two sections of a broader field that we might call *late technopower*. Like the side effects, it is essentially unmappable, but it centres on the imperative of subsuming various needs and desires under a technology for addressing the warming when it is too late. One can make out the contours of an emerging *mégabassine* paradigm of climate politics. Each technology has the capacity to set off contestation and antagonisms; and to the same degree, it runs the risk of being aborted. Humans might not bow down to it in the coordinated, well-mannered fashion called for. Precisely because they ask so much of people and nature, removal techniques could fail to materialise on anything like the necessary scale, leaving behind a graveyard of startups and pilot contraptions. In conjunction with default business-as-usual – even if it just keeps limping along, in a condition of less than total defeat – this would leave the planet sliding through the avalanches.

Third, negative emissions technologies are shrouded in uncertainties: about whether any carbon is actually drawn from the atmosphere; about the length of its captivity; about the relation between one tonne of emitted and

one of captured CO_2; about the utility of the undertaking if tipping points are crossed, and much more. With reference to such caveats, it has been proposed that removal should be subjected to a 'reality principle' – count negative emissions only 'when and where they actually occur'.[313] That this central concept of Freudian theory should have to be invoked in technical literature on carbon accounting, far from the pastures of psychoanalysis, suggests that there is something about removal that is not quite anchored in reality, something spurred by psychic processes internal to the subjects of capital. We might suspect that it has to do with magic, in the literal Freudian sense of the term.

Fourth, and perhaps of the greatest importance, every problem with a negative emissions technology grows with its scale. This is another truism. If BECCS is expected to remove 2,000 gigatonnes, it will do far more harm than if it has to shoulder only two; and the same goes for every other tech, with its respective damage function. The higher the concentration of CO_2, the more resources DAC would have to sweep up in order to star as an instrument crucial to the mission: the more electricity, heat, sorbents, steel, concrete, pipelines, basalt …[314] We can here discern a constitutive paradox of removal. *The same excess of CO_2 that makes it indispensable also makes it fiendishly difficult to accomplish*. Imagine the atmospheric concentration hits 1,000 ppm. At that point, removal by any means necessary might be humanity's only chance to cling to this planet. But by the same token, the enterprise would become prohibitively expensive, consuming so much productive capacity that little would be left for the species to live on.

Imagine, contrariwise, that emissions had ceased in 2009, at the time of COP15 in Copenhagen, at which time the concentration stood at 386 ppm. Then it would have been relatively easy to go back to 350. But at that point, early in the days of excess, removal did not appear so exigent. We might call this the necessity/impossibility paradox – the more necessary negative emissions technologies become, the more impossible – or, the double tragedy of overshoot.[315] Overshoot imposes on us the obligation of removal; and, to the same extent, it seems to rob us of the ability to fulfil it. The IPCC itself made an oblique acknowledgement of this quandary in its Special Report:

> Overshoot trajectories result in higher impacts and associated challenges compared to pathways that limit global warming to 1.5°C with no or limited overshoot (high confidence). Reversing

> warming after an overshoot of 0.2°C or larger during this century would require upscaling and deployment of CDR [carbon dioxide removal] at rates and volumes *that might not be achievable* given considerable implementation challenges.[316]

But the scenario of an overshoot up to something like 1.7°C was, of course, the strongest motivation for removal in the first place. Another way to formulate this double bind would be to say: because revolution was deemed unfeasible, the removal supposed to make up for its absence itself becomes unfeasible. And if this blockage might be realised already at 1.7°C, imagine its intensity at 2°C, or 3°C …

It follows, furthermore, that *the worst thing that can be done to negative emissions technologies is to use them to justify a prolongation of business-as-usual*. Every additional investment in fossil fuels makes their job more undoable. If one wishes to groom them for reversal, holding them up as a licence for continued fossil fuel investment does the greatest possible disservice to them – nay, it is an abuse that may render them inoperable. But in bourgeois society, this is precisely how removal was conceived from the very beginning.

10

Of Sewage Ideologues and Other Savants

So far, we have examined two possible configurations of removal: stop emissions and reverse the warming, or continue and reverse at some future date, the latter being the logic of overshoot-and-return. They have one predicate in common. For removal to work, emissions must be discontinued – immediately or with a delay, at some point, the tap has to be turned off. Trying to scoop out water if the bathtub receives ever more of it will be of little avail. The promise of programmatic overshoot was always to keep the faucet open for another while and *buy time* for the transition; a shut-off would have to happen, just not now. But these are not the only conceivable configurations. One can also imagine a relentless addition of CO_2 to the atmosphere matched by removal at the other end: tap open, drain widened, frantic scooping. Given what we now know about the constraints on negative emissions technologies, this third configuration seems to rule out reversal, or a progressive emptying of the bathtub. All available forces would need to be mobilised for the constant cancelling out of the positive. Levels would not drop. If another 40 gigatonnes are discharged every year, on end, the amounts of removal required to take them out *and* go back to the starting point would be so fantastical as to depart from plausibility. Overshoot would become a permanent condition, without return: we would have *continue and cancel out*: a formula for a stagnating excess.[1] But this might well be a best-case scenario, for, as we have seen, negative emissions may not have quite this capacity for cancellation. If they succeed in taking

out just parts of the ongoing additions, we would have *continue and ameliorate*: a formula for a steadily worsening excess. And this would still not exhaust the possible configurations.

'A spider conducts operations which resemble those of the weaver, and a bee would put many an architect to shame by the construction of its honeycomb cells. But what distinguishes the worst architect from the best of bees is this, that the architect builds the cell in his mind before he erects it in reality,' writes Marx; and the architects of removal have built their cells in the mind for nearly half a century by now.[2] All that imagining might well have effects in reality before anything is built. Merely the mental picture of millions of removal machines may insidiously, consciously or unconsciously, hold sway over the agents who own or otherwise control the means of production. Down the road, the picture says, there will be obverse technologies to bail us out. Fossil fuels are not that much of a problem, because of the *imaginary* existence of removal, and so we might as well keep setting them on fire. This effect is sometimes referred to as 'mitigation deterrence': because of the *promise* that those technologies will appear, like a house from an architect's drawing board, emissions cuts in the real world are rendered less urgent, disincentivised, deterred.[3] Ultimately, they might be redundant. If the promise is sufficiently inflated, there might be no reason at all to get off fossil fuels. But ultimately, of course, the cells built in the mind might also never be erected in reality – a possibility that inheres in the ontological distinction between human technologies and those of spiders and bees – which would leave us only with the fossil fuels. Removal would then do its real work *in posse* not *in esse* and could go on doing it practically forever, as long as the drawing dangles in front of the agents. Here, it would be *continue and continue and continue* … – or negative emissions technologies negated into so many *positive* emissions technologies.

We can thus distinguish between at least five configurations: stop and reverse; continue and reverse; continue and cancel out; continue and ameliorate; continue and continue. The slope on which they sit is exceedingly slippery. The technologies in question might lend themselves to either of the five and move between them, depending on the balance of forces on the slope. They could initially be put forth for the first configuration but end up working hard within the fifth. If we delve into the period of ideational gestation, however, we find something else: *removal*

was, from the very beginning, advanced as a means to prolong the fossil fuel era, for anything between a good while and into eternity. When the architects built the cells in the mind, *the purpose was to enable more extraction and combustion of fossil fuels*, if only for a few decades … or a century … or with no end date at all in sight. Even if formulated within the second configuration, the emphasis was on removal shielding capital from imminent destruction. Even if only conceived for an interval, its *raison d'être* was capital protection. And once that purpose was nailed down, there was no stopping the slide into continuation ad infinitum.

Brains not brawn

When Freeman Dyson proposed the planting of trees, he acknowledged that, some day, time would be up for fossil fuels. 'The long-term response' to 'a CO_2 disaster' would have to be conversion to biofuels, nuclear, geothermal and 'direct solar-energy': it was just that no such thing could happen in the near term. Dyson sought a way to 'buy time'. How much of it? He deemed it 'inevitable' that fossil fuels would be used 'for many decades', and in increasing amounts to boot; hence plantations would have to sop up not only existing emissions but the much larger ones to come – 'several times the present value'.[4] In the 1970s and '80s, removal was widely imagined as a stopgap measure. Because it would take a long time to wean the world-economy off fossil fuels, trees would have to pick up the slack.[5] Another of the un-spidery architects admitted that 'ultimately, the only way to prevent the CO_2 level from rising is to stop oxidising fossil fuels', but dependence on such fuels made this a 'formidable' challenge. There would have to be trees for the nonce, so as to 'prevent further CO_2 buildup without shutting down the global economic system'.[6] Fossil fuels would eventually pass away, in a natural death caused by resource depletion or market dynamics. What could not be countenanced was some form of euthanasia, an intervention in the present that would actively end the fossil economy – there could, in short, be no capital destruction.

We should note that this moment of gestation coincided with the maturation of climate science and the creation of the institutions of climate

diplomacy. The moment in time when the IPCC was formed, the UNFCCC signed, the COPs commenced was also the moment when removal began to be imagined as an escape clause. The basic coordinates of climate politics were here laid down for later. In 1991, one prominent research institute convened a meeting with energy experts to talk shop on CO_2: the chroniclers of the event noted down 'all the difficulties expressed at the meeting in reducing energy sources of carbon emissions'; and because of these, it was 'not surprising that energy experts see massive afforestation as a great opportunity for removing the large amounts of CO_2 emitted'.[7] (Of course, one would have to solve the problem of permanence to 'break nature's cycle' – the decaying of trees – that so 'reduces the effectiveness of carbon storage'. But here innovative solutions presented themselves: 'Maybe the final answer to this key question lies in copying nature's strategy on a geological time scale, burying whole forests to make artificial coal beds for distant generations.'[8] Coal mines cannot be closed, but new ones can be engineered – *vide*, the wood vault.) Plantations would allow the world to circumvent the problem of overaccumulation of CO_2, without having to take on any of the difficulties.

The logic of the quick fix was enunciated by another study from 1991: a transition away from fossil fuels 'would be fiercely contested'. At this point in time, 22 gigatonnes were lofted into the air every year. Nearly one quarter came from the US, and so 'the most visible obstacles' would be raised in that one nation, largely stemming from the cars Americans like to drive so much. 'By now some degree of global climate change is inevitable'. Something must be done, however; and thankfully, techniques for drawing down CO_2 through photosynthetic routes offer 'less expensive and less painful solutions'. They would 'provoke less resistance than radical proposals to tax economic growth or to proscribe the burning of fossil fuels'.[9] Little was done to blunt the syllogism: we cannot do anything about the recalcitrant interests vested in fossil fuels – in the US in particular – yet we must do something; hence let us think about planting trees. We can here see overshoot ideology in embryo, three decades before its delivery into the conjuncture. What is remarkable, of course, is that the image of negative emissions technologies was invoked as a reason to abstain from confronting the source of the problem, at a point when this source had released a cumulative amount about half as large as in the early 2020s and kept

releasing it at roughly half the rate – that is, *when it was still comparatively easy to shut down that source*. But the image said: we can keep it going.

John Martin the Baptist and Iron Man imagined along the same lines. 'If fertilisation were used', he wrote, 'it would have to be carried out until fossil-fuel emissions were drastically reduced (hundreds of years); thus, it represents a Faustian bargain at best' – an honest admission of the nature of the deal and a telling, and all-too-common, assessment of the lifetime of fossil fuels in capitalist society.[10] They will stay with us for *hundreds of years*. To one worried critic, Martin responded: 'I agree that the ideal would be to have the average American get out of his car; have the Chinese not develop their coal resources; have the Brazilians not cut down the rain forest. However, we don't live in an ideal world.'[11] Hence a tanker of iron it had to be. James Lovelock proposed artificial upwelling because 'the inertia' of 'our response' to the climate problem makes it 'doubtful that any of the well-intentioned technical or social schemes for carbon dieting' will work: so imagine millions of mega-straws for the algae. One chemist pondered how the full development of ocean-based removal could maintain 'our ability to continue use of the fossil fuels that supply abundant energy for our economy'; this might just be 'the price we pay for living in a technologically advanced society'.[12]

Virtually every negative emissions technology seems to have had a similar origin story (BECCS very much included).[13] Here is how Walter Seifritz began his pitch for enhanced weathering: 'If fossil fuels are to be used on a massive scale and the greenhouse effect avoided, carbon dioxide emissions into the atmosphere must be reduced. One way to achieve this is to collect the CO_2' by means of silicates: the unalterable premise being that fossil fuels *are* to be used on a massive scale, apparently a deep conviction of the Swiss.[14] A devotee of 'hard' energy infrastructure (including nuclear), sceptical of the potential of decentralised solar, he questioned the desirability of emissions cuts.[15] 'The fact is that in the next century mankind needs the energy from the fossil fuels,' he factually observed in 1995.[16] And yet all that CO_2 cannot be left untreated. Apart from silicates, Seifritz considered turning excess CO_2 into massive, 400-metre-wide marbles of 'dry ice' that would degrade over centuries – another solution that seemed 'remote but feasible' compared to closing down the source.[17] Nothing of the latter kind would now need to happen. A 'new philosophy'

in energy management would embrace 'cheap fossil fuels with CO_2-disposal' – a combination 'economically superior to a system based e.g. on a [*sic*] extended use of renewable energy sources'.[18] Nuclear would here star as the hard housekeeper of fossil fuels, with a boundless capacity to deploy silicates or dry ice or some other favoured material. Ceaseless 'exploitation of fossil fuels' plus nuclear-powered technologies for collecting and disposing of CO_2: behold 'the optimum of the "careful and prudent use of the carbon atom"'. Such an arrangement would 'decarbonise the fossil fuel cycle', so that the 'greenhouse problem must not necessarily mean the end of the fossil fuel era'.[19] It would be the best of both worlds: a fossil-fuel era without end and a climate without disruptions.

Before Dyson, Martin, Lovelock, Seifritz and the others in the long line of white men, there was Nordhaus the primal father of bourgeois climate economics. In his first paper from 1975, he juxtaposed – a highly original move at the time – geoengineering and removal against mitigation and argued that the latter would cause pain by cutting the 'royalties' from coal and oil to zero. An alternative would be to 'clean out the carbon dioxide from the atmosphere *ex post*. This approach would rely on the possibility that removing the carbon from the air by a natural or industrial process is *cheaper than refraining from putting the carbon in the atmosphere in the first place*.'[20] Putting the carbon into the deep ocean would be especially cheap. Some fall in global emissions might have to be induced around the year 2020; but in any case, 'we can be relatively optimistic about the technical feasibility of control of atmospheric carbon dioxide.'[21] Come 2020 and no fall was induced, but optimism about negative emissions technologies reached an all-time high.

Back in 1991, Nordhaus reminisced about his grandfather's advice to 'use brains, not brawn' when facing a seemingly insurmountable challenge. 'Reducing fossil-fuel use through trillions of dollars of investments' amounted to brawn because it would be too costly. Against this stood 'a promising new approach to the threat of greenhouse warming', namely 'to use our brains to find a way to offset greenhouse warming through climatic engineering' – the 'global equivalent of turning on an air conditioner'. Nordhaus spent one whole sentence highlighting the potential risks with using our brains in this way – noting the need for further studies – and several paragraphs about the potential exploits. In addition to

geoengineering, he now took up the cudgel for iron fertilisation: both had the great benefit of being ‘more cost-effective than plugging the oil wells and shutting down the coal mines’; and the latter technology ‘might well annually remove from the atmosphere a quantity equal to current CO_2 emissions’. He blurted out that ‘these proposals surely sound like panaceas’.[22] During the three decades that followed, no planetary-scale tree planting or enhanced weathering or iron fertilisation was, of course, put into action. But the architectural *image* of panaceas other than closing down the source was firmly established in the interior, and working its way out into reality.

The founding father goes to the loo

It fell to Klaus Lackner to pull these threads together into something like a philosophy. In his first paper on enhanced weathering, he made clear the virtue of this technology: it would ‘allow utilisation of the large known fossil-fuel reserves while avoiding build-up of atmospheric CO_2’.[23] The argument was elaborated in an extensive report to the Los Alamos National Laboratory in 1997, soon after passed on to the US Department of Energy. It spelled out the great danger looming on the horizon. ‘The political pressure to curb carbon dioxide emissions into the atmosphere is gradually rising,’ as manifested in IPCC reports, COPs and various legislative initiatives. ‘Regardless of its scientific merits’ – an innuendo pandering to the denialists – this trend ‘poses a significant economic risk to the fossil fuel power industry and the coal mining industry’. More specifically, ‘at risk are *investments on the order of a trillion dollars* in power plants, mining and associated infrastructure’, a figure derived from the capital sunk only in the US.[24] Apart from the imperative of protecting such investments, there was the case for fossil fuels as essential nutrition. They alone, claimed Lackner and colleagues, are cheap enough to satisfy the energy needs of a growing population and dissuade it from disorderly behaviour. ‘There is no good alternative to fossil fuels’: solar and wind have not been demonstrated at scale and remain hopelessly expensive.[25] But political interference could make fossil fuels artificially uncompetitive, and it was this threat Lackner et

al. wanted to pre-empt, by drawing up plans for turning the gas into stone. The reasoning is worth quoting at length, here from the report submitted to the US government:

> The purpose of this technology is to maintain the competitiveness of coal energy [the original report said 'fossil fuels'], even when in the future environmental and political pressures will require a drastic reduction in carbon dioxide emissions. In contrast to most other sequestration methods, this is not aiming at a partial solution of the problem, or at buying time for phasing out fossil energy. Instead, the goal is to obtain a complete and economic solution of the problem, and thus *maintain access to the vast fossil energy reservoir*. Such a technology will guarantee energy availability for many centuries even if world economic growth exceeds the most optimistic estimates.[26]

Here the slide from the second configuration to the third, already prefigured by other architects in the early 1990s, was made explicit: no longer some version of overshoot and return, Lackner envisioned a cycle of continuing and cancelling out. It could be endlessly extended. There would be no expiry date. Lackner and his team 'did not just aim at reducing the pain of phasing out fossil fuel', but at forestalling such a phase-out altogether.[27] If the CO_2 emitted through combustion were brought back to Earth as solid rock, there would be nothing to blame the industry for, and the many trillions of dollars could safely yield their expected revenue.[28] The begetters did not beat around the bush – the reports from Los Alamos were given titles such as 'Keeping Coal Competitive' and 'Protecting the Future of Fossil Fuels Under Global Climate Constraints' – and when Lackner shifted his attention to DAC and became its founding father, he stuck to the line.[29] The first paper was submitted to a conference on coal utilisation.[30] It gave this business the gift of eternal life. Coal deposits were estimated to contain nearly 40,000 gigatonnes of CO_2 – 1,000 times the annual emissions of the early 2020s – the release of which would push the atmospheric concentration up to 4,700 ppm in the absence of waste disposal.[31] Bring it on: DAC will wash out the gas. It was expressly conceived as a technology for driving over and beyond all barriers.[32]

Thus the cell was built in the mind and brought to the wider world. DAC, Lackner explained to the readers of *Science*, is how we 'render fossil fuels environmentally acceptable'. He flaunted his abiding concern for the capital fixed in mines and pipelines and airports and cars, now hanging in the balance: here is how all that infrastructure can 'live out its useful life'.[33]

DAC would, he informed the readers of *Scientific American*, 'allow cars, planes and ships to continue burning liquid fuels' and make regulations unnecessary.[34] He again professed his pessimism about renewables and, in particular, electrical vehicles as 'far off'; instead his own mechanical trees and Global Thermostat showed what had to be done.[35] 'Given society's present reliance on fossil fuels, widespread adoption' of DAC is 'indispensable', he told the readers of *PNAS* – the keyword here being *given*.[36] In an essay called 'Free-Market Approaches to Controlling Carbon Dioxide Emissions to the Atmosphere', he contended that 'prohibiting the use of fossil fuel would not be practical', as it would decommission infrastructure before the end of 'its intended lifetime': but DAC made the problem disappear as though by the waving of a wand.[37] Lackner even believed it possible to cancel out all the emissions from unceasing business-as-usual *and* revert to bygone atmospheric concentrations of CO_2. There was nothing that DAC could not do.[38] If anything held together Lackner's *Weltanschauung*, it was the refusal to accept limits in any form: there must be no limits to fossil fuel extraction; there will be no limits to the achievements of DAC; technology is a force smashing through external limits; the world can be given over to the auxons.

But Lackner was at his most visionary when he developed a new metaphor for removal. In a paper from 2017 – the year when the first DAC plant opened on the rooftop in Hinwil – he proposed that we should approach climate change as a 'waste management problem'.[39] This in itself was not an entirely new idea; forty years earlier, the Italian physicist Cesare Marchetti had suggested that we treat fossil fuels much like nuclear fuels, by capturing the waste and disposing of it somewhere safe and out of sight (he favoured the deep oceans).[40] Lackner now struck on the image of CO_2 as the atmospheric equivalent of sewage. The act of emitting it is like the one you perform on the loo. DAC devices would be toilets for flushing out the excreta. For some reason, metaphors for CO_2 are drawn to the bathroom; but there is a political difference between the bathtub, which is meant to visualise the *limits* that inhere in the cumulative character of climate change, and the toilet, which suggests a limitless loop. Moreover, the faecal imagery turns CO_2 emissions into a 'metabolic by-product', rather like shit. Wishing them gone would be an affront to the human

digestive system. Asking people to cease burning fossil fuels would be like telling them to stop pooping – or, in Lackner's own words: 'Rewarding people for going to the bathroom less would be nonsensical.'[41] He here affected a full-blown naturalisation of fossil fuel consumption. Among its curious implications would be that rich Americans must have intestines and turds several thousand times larger than poor Mozambicans.[42]

DAC, then, would treat CO_2 as just one more natural effluent. It would discard the presumed moralism of mitigation. 'A waste management perspective makes it unnecessary to demonise or outlaw activities that create waste streams. It's okay for people to use toilets' – the whole problem redefined; the only wonder now being why the toilets haven't yet been constructed in the tens of millions. Nothing would need to be destroyed. Installing a toilet inside a temple does not presuppose that it be razed to the ground. The existing energy infrastructure can be left in place; 'only the construction of a parallel infrastructure' is required. It can be accomplished by private contractors building the lavatories. Unlike attempts to cut back on combustion, it 'does not threaten the political, social, and economic interests associated with the fossil energy system – and does not automatically trigger opposition from those interests'. In fact, worldwide sewerage is the royal road to saving their 'entire business model'.[43] On top of this, the technology can also be used to clean up past emissions, like toilets retroactively inserted under the defecators: DAC can 'scale up nearly without limit'.[44] We now know this to be a delusion.

It is difficult to overestimate the influence of Klaus Lackner on DAC. Indeed, it is 'hard to think of another field that is so much the product of a single person's thinking and advocacy', in the informed view of David Keith; perhaps some religious cults might come in for comparison.[45] And his influence extends beyond DAC to removal in general: Odlin of Running Tide testified to an epiphany at a talk by Lackner, 'the physicist who popularised the idea of removing carbon from the atmosphere. It clicked. "It was like, Oh, this is right because there's no way we're going to get off fossil fuels in the next 50 years", he recalled thinking.'[46] Lackner himself was, of course, promiscuous about technologies. In addition to enhanced weathering and DAC, he imagined strips of land covered with material absorbing CO_2; running from 'from pole to pole', they would be protected by walls or fences. Such global corridors would likewise be 'friendly to

established industries' and 'nonthreatening to inertial energy use infrastructures'.[47] As of this writing, that particular idea is still waiting for its first startup.

Perhaps the most highly esteemed follower was Wallace Broecker, a lionised scientist of the climate system, student of AMOC and non-linear change. He befriended Lackner in the early millennium and converted to his gospel. Together, the two men spread it to Iceland. With the blessing of that country's president, they had a hand in the founding of Carbfix, the company that would become the storage partner of Climeworks. Broecker gave his teacher's metaphor a more strictly alimentary content: burning fossil fuels is in 'direct analogy to eating food'.[48] The cesspool that hovers above us just needs to be drained into the ground in Iceland and elsewhere. Fossil fuels are here to stay for centuries; a whole planet of 'power plants and refineries and pipelines and gas stations' is built around them; renewables are not an alternative, seeing as electricity from solar costs twenty times as much as that from coal.[49] But 'thanks to Lackner, it now seems possible that, as far as fossil fuels are concerned, we really might have our cake and eat it too,' Broecker consigned his insight to paper.[50] Here was the saviour of 'our wonderful gadgets', notably automobiles.[51] A turn to DAC 'recognises that fossil fuels aren't going away' and therefore 'should appeal to oil and coal companies, which aren't going away either'.[52] We shall presently see just how right Broecker was on the latter count.

On having the cake

As revered as Lackner might have been, he was not alone in developing the philosophy: Keith contributed too. Around the turn of the millennium, he was searching for a way to enable the 'use of fossil fuels without atmospheric emissions of carbon dioxide'.[53] He spoke of it as 'carbon management' and, at this point, still had good old CCS foremost in mind. This technology promised to cut the bond between fuels and emissions and make it possible 'to consider a fossil-based global economy through the next century'.[54] It would appease the powers that be. 'By reducing the severity of the threat that emission reduction poses to fossil industries and

fossil-rich nations, ICM [industrial carbon management] may ease current deadlocks in both domestic and international abatement policy.'[55] Do not threaten the master; just give him a golden toilet to sit on.

Like Lackner, but in more detail, Keith also poured cold water on hopes for solar and wind as substitutes for fossil fuels: they were simply far too unwieldy and expensive. Photovoltaics did not, he and his colleagues argued in 2008, stand a chance of becoming competitive with other sources of electricity *within the next forty years*, and so it would be misguided to lavish subsidies on them.[56] As for wind, it was supposedly nowhere near cost parity with coal (as of 2001). Keith held it to be an intermittent, sparse source of electricity unsuitable for mass rollout.[57] He even made the singularly extreme claim that wind turbines would alter the local climate and raise temperatures more than the fossil fuels they were set to displace.[58] As he turned towards DAC, he alleged that this technology had none of the drawbacks of the renewables – above all, it would be cheaper.[59] Unlike them, it did not quite exist yet. But this was a minor detail, for 'several strong arguments suggest that it will be comparatively easy to develop practical air capture technologies' (with references to Lackner's texts).[60] DAC has 'important structural advantages' over solar and wind, not the least its eminent compatibility with the present order. It would give a new lease on life to business-as-usual. Or, in the clearest possible terms, '*it is optimal to pollute more when it is possible to clean up afterward*'.[61]

If this was the view from Carbon Engineering, the two souls behind Global Thermostat put the emphasis on the distinction between the long and the short run. In the long run, the solution is to switch to renewables. But this is so distant a prospect as to vanish into the fog of the future. In the short term, no transition can come into play: 'We cannot eliminate fossil fuels from our economy overnight,' in the words of Graciela Chichilnisky, the lone founding mother among all the men.[62] Why not? 'A quick and drastic reduction in emissions is not feasible due to the sheer size of the fossil infrastructure'; more precisely, this infrastructure is worth 'about $40 trillion today, *and with current trends about $400 trillion by the end of the century*'.[63] Some fix is needed to accommodate those current trends and let the trillions multiply. A long time must pass before fossil fuels 'have depreciated their investments' (especially given the foreseen continuation of such investments).[64] Prematurely knocking that capital out, while raising

the astronomical sums requisite for scaling up expensive renewables, would spell economic catastrophe.[65] The mission graciously taken on by Chichilnisky was therefore to save profits and planet in one stroke, 'in the short term *allowing the continued use of fossil fuels* and simultaneously *decreasing the carbon content* in the planet's atmosphere'.[66] Towards the end of this long-drawn-out period, there would, presumably, still be a shift to renewables.

Or would there? Suppose that humanity actually develops a planetary infrastructure 'allowing the continued use of fossil fuels' without any concomitant rise in CO_2 concentrations. After such an accomplishment, would it decide to forego said fuels? Chichilnisky here made an implicit appeal to what we have called rationalism-optimism, or the idea that a technology for cancelling out the climatic effects of fossil fuel combustion will be used rationally and optimally: the agents in charge will not fall for the temptation to keep burning everything down. The fix will be used just for a short run, and then policymakers will do as reason dictates. We shall examine this notion closer below. Suffice it to say here that it was belied by the constant slide into the third configuration among Chichilnisky and her colleagues, including her partner Peter Eisenberger, who argued that DAC would 'close the global carbon cycle', 'enable us to drive our cars while cooling and fertilising the planet' – always the American cars – and realise 'the enormous cost benefit of staying with carbon-based fuel'.[67] Here was a solution for the ages. The idea of Global Thermostat was to set the preferred temperature on the planet and even buffer against natural variations in solar insolation. There would be no more glacial cycles. Thousands of years into the future, the New York metropolitan area would be saved from advancing ice caps, the cars still rolling.[68] Less given to scientific (or pseudo-scientific) eccentricity, the CEO who took over Global Thermostat after Chichilnisky's departure reverted to simpler words: 'I don't think anybody believes that all of a sudden, you know, the world is going to stop using oil and gas. I would love it if they did, but it's just not feasible,' so invest in DAC.[69]

In the original triumvirate, Climeworks was the most politically sophisticated, least inclined to hubris, most careful to stay within the second configuration. But even that company would occasionally slip into the third. One of its representatives explained to us when we interviewed him in

Zürich: ‘We have tried climate policy for, what is it, forty years now, based on abstinence. It hasn’t worked. If the only solution you offer is to stop flying, to stop eating meat, to stop driving a car, you won’t get people on board’ – these being essential components of ‘lifestyles that especially those in industrialised countries have become accustomed to’.[70] Life with DAC comes without the duty to abstain. Those who fly the most and drive the most and eat the most meat are likely to be the first to jump at the opportunity.

The distinction of the worst architect

How harsh should our judgement be of these architects of the mind? We could give them the benefit of the doubt, because – so one could argue – they could not possibly know all that we know today. Around the turn of the millennium, it was not yet evident that solar and wind would soon become the cheapest sources of electricity across the board. Maybe the deference to the status quo could be excused by the patchy state of knowledge at the time? Perhaps the irony of privileged white men from the 1970s onwards dismissing ambitious climate politics – when comparatively speaking there were still oceans of time, and when a relatively gradual reduction in emissions could have kept the demons at bay – was nothing more than a historical accident? A show of naivety grounded in all-too-human ignorance? But Lackner wrote his toilet paper in 2017, when everything he needed to know was already known: by that point, solar and wind had undercut fossil fuels. All that remained were the trillions of dollars sunk in the latter. And philosophising along the sewage lines continued well beyond this point – renewables cheaper, but masses of capital fixed in fossil fuels – as even a cursory reading of the literature would show.

If this literature did mark a shift, it was one of subtle nuance rather than content: fewer outright attempts to ‘keep coal competitive’, more silent acquiescence to the powers that be. ‘The excessive dependence on fossil fuels for the daily energy needs of our growing society [*sic*] has led to the accumulation of copious amounts of CO_2,’ began one state-of-the-art review in 2022; and because of this unconquerable excess, DAC must be adopted ‘to close the anthropogenic carbon loop’.[71] Around this time, the

IAMs, hitherto ridiculously faithful to BECCS, finally opened their arms to DAC. Modelling produced the unsurprising result that DAC 'delays the phase-out of fossil fuels', since it 'acts as a backstop technology to fulfil climate ambitions'.[72] DAC 'results in larger emissions until around 2070'.[73] Of the greatest import, it can 'avoid immediate stranding of fossil fuel assets and benefit energy-exporting countries by preserving the value of their fossil fuel reserves' – the toilet logic – for an indeterminate amount of time.[74] In 2021, one IAM team found that DAC would be far more effective in postponing and reducing asset stranding than any tree-based alternative: it would save about half of all capital at risk from destruction under 2°C. To perform such a rescue operation, 30 gigatonnes needed to be taken out per annum. 'DAC availability would allow for a less stringent reduction in committed CO_2 emissions' – pollute more, then clean up afterwards.[75] (Or just learn to wipe your butt and flush, for heaven's sake.) IAM exercises for individual nations demonstrated that DAC would let Canada produce oil from its tar sands and Saudi Arabia from its peerless holdings for many decades more.[76] Such modelling was still conducted within the second configuration, but the lure of the third was never far away. Nor was the vision of the auxons. In 2016, one study resurrected Lackner's first stroke of genius and proposed that armies of artificially intelligent robots be tasked with the manufacturing of DAC devices, bound to thereby become dirt cheap and capable of reversing climate change.[77]

We seem to be dealing with a syndrome. The apportioning of pessimism and optimism between the options on offer had nothing to do with technology as such, in any neutral sense of engineering or design feasibility. Were that the case, these people would not have disparaged solar and wind while extolling DAC – or enhanced weathering, or strips running from pole to pole, or your favourite pick. In hindsight, we may, in fact, identify this as a constant in over half a century of literature on removal: wrapping the planet in plantations, mixing up the oceans, burying the gas in basalt and any other brainy-brawny solution appears instantly within reach, available at the snap of a finger, to be scaled on a whim. But emissions cuts could only, possibly, maybe happen somewhere towards the misty end of the century. In this regard, the situation in the 2020s was identical to that in the 1970s: the prophets of removal still argued that it would be possible to go from near zero to gigatonnes in a decade or so – the kind of mega-leap they

had ruled out for renewables all along. It takes no superior intelligence to spot the significant difference. A real transition would not be kind to capital. But removal could. The very reason negative emissions technologies seemed so easy-breezy was also the reason that phasing out fossil fuels appeared to be rocket science. Daring and delay were two sides of the coin of capital protection.

When the last history of global warming is written, the most concrete, real-world effect of removal might well be dated to this half a century of ideation. Thinking about the second and the third configurations – and sliding between them – folded into mitigation deterrence, so that, during a critical period in the history of the planet, dominant classes were given one more reason to continue and continue and continue. Negative emissions technologies had actual impact on atmospheric concentrations of CO_2, not by dint of their existence but by virtue of their not existing other than as a chimera. It is, of course, in the nature of such causation that it cannot be precisely measured. We shall revisit this methodological problem below. For now, we can only recognise the possibility that all those technologies peddled as instruments for dealing with the climate crisis when it is too late *instead contributed to making it too late*. What was meant to reverse climate change conduced to it becoming irreversible. Raising these cells in the mind was not an innocent practice, without contact with reality – and here we might have to append a clause to Marx: what distinguishes the worst architect from the best of bees is that his creation may affect the material world *while still only being an idea*. Beehives and spider webs do not first exist as ideologies.

The scene that has played out over the past half century is one of architects building an imaginary bridge – sometimes as a temporary solution, other times as a permanent foundation – so attractive as to spur the traffic on to nowhere, or into the abyss. Emissions cuts were relegated to an afterthought, at best a token acknowledgement that yes, eventually, we also need to do that. Removal was the way into, not out of, the overshoot conjuncture. Can it possibly be turned around into an exit? That would require wresting negative emissions technologies from the hands of fossil capital. But those hands already hold them in a very firm clutch.

11

We Are Going to Be Forever Driven by Value

‘Ultimately I refer to direct air capture as the holy grail,’ said Darren Woods, CEO of ExxonMobil, to a business conference in June 2023.[1] It was not the first time he had said this. He began using this expression in the middle of 2022, a very special year in the annals of ExxonMobil and primitive fossil capital as a whole: DAC, ‘to my mind, is the holy grail’.[2] By the time of an earnings call in early 2024, when the boss yet again repeated the line – ‘as I’ve said many times before, the holy grail in addressing emissions is direct air capture’ – it was a well-worn mantra.[3] The words were backed up by the installation of a small pilot unit at the enormous petrochemical complex in Baytown, Texas, where ExxonMobil would test its own proprietary chemical liquor and examine whether it would be worth scaling up to the level of a facility.[4] The public communications began to fill up with DAC. ‘Removing CO_2 directly from the air? Yes we are! You heard that right,’ bragged the company website.[5] This technology is ‘essential, in the view of experts, if we are to arrive as a society at net zero in the future’, averred the 2023 ‘progress report’ on ‘advancing climate solutions’, citing the IPCC and throwing in BECCS for good measure.[6] In anticipation of that future, ExxonMobil acquired CO_2 infrastructure across the Southern states, including the pieces that ruptured: ‘We’ll see more and more deals that bring emissions into that pipeline.’[7]

There was a prehistory to this moment. In the late 2010s, ExxonMobil drove an advertisement campaign through the digital highways: ‘Plants

capture CO_2,' said a typically seductive voice-over, as the chlorophyll blended into immaculately white chimneys and factory buildings – 'what if other kinds of plants captured it too?'[8] The company promoted CCS and algae.[9] It funded, as we have seen, the earliest research into ocean alkalinity enhancement, as well as the first assays by Peter Eisenberger. Once the latter had set up Global Thermostat, ExxonMobil formalised a partnership with it. Eisenberger was thrilled to work with his old colleagues – 'we recognise our shared objective' – and Chichilnisky had not a bad word to say about them: 'I'm not telling these friends what to do.'[10] What did the giant get out of its affair with the dwarf? 'Current and former staffers [of the latter] say it's unclear exactly what Exxon is doing with Global Thermostat besides advertising it heavily,' reported *Bloomberg*.[11] After the crisis in the startup, the big patron stayed with it for another couple of years, before breaking up and taking its dalliance with DAC into its own business.[12] It also advocated natural climate solutions. It claimed to run a project for grassland restoration in the Permian Basin, the heartland of primitive accumulation of fossil capital in the US.[13]

All the while, ExxonMobil was, of course, barrelling on. Just weeks before he began trotting out the line on the holy grail, Woods told shareholders that its output of hydrocarbons would increase by one tenth in only the three next years.[14] 2022 was the *annus mirabilis* of an all-time profit bonanza.[15] But 2023 was not bad either. Profits remained astounding; as one business observer put it, years of aggressive investment in high-return projects – notably the oilfields of the Permian Basin and Guyana – had turned ExxonMobil into 'a moneymaking machine'.[16] 'By any measure, our plans have and will continue to deliver exceptional value,' Woods swaggered.[17] At this point in time, the two countries in the world that posted most new oil and gas projects were the US and Guyana: ExxonMobil was the prime mover in both.[18] What was it, then, about removal in general and DAC in particular that so beguiled this company?

'We think it makes a lot of sense to … rather than tear up and throw away the existing infrastructure and the industries that we have in place that are intensive energy users, that we find a way to deal with the problem, which is the emissions,' explained Woods, with reference to the DAC project in Baytown.[19] At the annual festivities of his circuit in Houston in 2024, he reiterated the distinction: 'I think one of the challenges is the way the

problem has been stated in the past: “We need to get rid of fossil fuels and [*sic*] natural gas, crude and coal.” And I think what we should stay focused on is: “We need to get rid of the emissions associated with the combustion of those things.”’[20] But Woods made it very clear that DAC was at this stage *only an idea*.[21] ExxonMobil was putting money – it never disclosed how much – into an ideational entity. We might here take the holy grail as more than an innocent idiom: in Arthurian romance, it is a magical object with the power to heal and provide eternal life. ‘As in a dream I seemed to climb,’ Lancelot describes his search for it in *Idylls of the King*.[22] One historian sums up the storyline: ‘A mysterious vessel or object which sustains life and/or provides sustenance is guarded in a castle which is difficult to find. The owner of the castle is either lame or sick and often (but not always) the surrounding land is barren.’[23] The holy grail came into currency as a response to the fall of Jerusalem and the other defeats suffered by the crusaders.[24]

The coming of carbon neutral oil

There would not be a logic to this dream if it were not also broadcast by the competitors. Chevron was an early investor in Carbon Engineering as well as Svante (after Arrhenius).[25] It put one egg in the BECCS basket: a project in California that would supposedly store hundreds of thousands of tonnes once operational (date unspecified).[26] Moreover, ‘in collaboration with Acorns, a saving and investing app in the United States, Chevron is piloting a new program in California to have five trees planted via the One Tree Planted organisation every time an Acorns account holder fills up at a Chevron gas station.’[27] The corporation joined something called Markets for Natural Climate Solutions.[28] Together with a foundation by the name of Restore the Earth, it planted cypress trees on a property in Louisiana.[29] But the mother ship was Gorgon – yet another mythological parapraxis – advertised as the largest CCS installation in the world; it captured and sequestered CO_2 from a gas field next to a nature reserve in Australia.[30] It was seen by many as a litmus test for CCS and, by extension, the up-and-coming BECCS and DAC twins. (Two passive scholars at MIT welcomed

Gorgon as a life vest against asset stranding.[31]) It turned out to flop. CO_2 could not be buried in anything like the promised amounts. The underground storage looked shaky. Emissions from the gas field itself – consumption uncounted – grew by one half, when Gorgon was meant to eradicate them.[32] *Bloomberg* visited the site:

> Get within a few dozen meters of one of the world's biggest carbon capture projects on Australia's remote Barrow Island, and normal conversation quickly becomes impossible. Emanating from the dense maze of pipes and towers the size of a city block is the roar of carbon dioxide escaping into the atmosphere – exactly what Chevron Corp.'s ambitious $2.1 billion system was supposed to stop.[33]

Yet, knuckles white, Chevron kept to its faith: 'A decrease in overall fossil fuel emissions is not inconsistent with continued or increased fossil fuel production,' and increase fossil fuel production Chevron faithfully did, by, for example, one tenth in the Permian Basin in 2023 alone.[34] It pledged to grow total output by *at least* 3 per cent every year in the mid-2020s.[35] Booming profits drove this spiral of expanded reproduction to new heights, as elsewhere in the circuit.

ConocoPhillips hooked up with Avnos, the startup capturing carbon and water from air. So did Shell.[36] Shell funded the Arizona labs of Lackner.[37] Shell backed RepAir of Israel.[38] Shell had a kink for natural climate solutions, restoring forests, grasslands, wetlands and putting carbon into the soil in Australia; like Chevron, it offered customers the option of having CO_2 removed when filling up their tanks.[39] Total seemed behind on DAC but keen on trees in Congo and Peru and sundry exercises in CCS.[40] BP published reports about the whole panoply of negative emissions technologies. It drew up scenarios plotting how necessary they are.[41] Repsol claimed to be 'investigating' them all, while planting some trees in Spain and talking up DAC and publicising the first DAC project in Latin America.[42] ENI invested in Captura, the startup extracting CO_2 from the ocean.[43] So did Equinor.[44] The CO_2 drawn out of seawater under the auspices of the latter would be piped into the Northern Lights, an 'open-source' storage system, ready, from 2024 onwards, to receive captured gas from anywhere in the world and inject it into the Norwegian shelf. The vision here was for pipelines to point to Europe's largest oil and gas

producer, positioned to cash in on the storage of the CO_2 previously released into the atmosphere. The Northern Lights would be a bank vault in the seabed off Bergen. (Shell and Total were on board.)[45] Equinor also fancied RepAir of Israel, as well as the sinking of seaweed.[46] Aker BP looked into kelp farms in the waters off Norway, while Lundin Energy – the post-Nazi oil company that was Sweden's finest gift to the fossil economy (possibly with competition from BECCS) – said that it was planting trees in Ghana.[47] Lundin reached the thaumaturgical heights of selling 'carbon neutral oil' from Johan Sverdrup, the largest oilfield in Europe.[48]

All of these companies were party to the spiral of constantly expanded reproduction. All were undertaking verifiable enlargement of fossil fuel assets, and all were mouthing words about efforts in the removal business, the substance of which was spurious. But none approached the audacity of Occidental.

The coming of carbon negative oil

When an oil well is opened, the fluid comes out by itself, as if it had been waiting all these millions of years for the chance. But as more and more leaves the well, the remainder becomes shy and reluctant to go: 'artificial lift' has to be implemented.[49] The extractor can no longer rely on natural pressure. The product must be coaxed to the surface. In 1972, Chevron hit upon a novel method for dragging out the oil that refused to come: taking pure, concentrated CO_2 and driving it into the bottom of a well. Like a spurt of foam or soap, the CO_2 would ease out the oil, making it less viscous, prodding it to flow towards the borehole.[50] Chevron had invented 'enhanced oil recovery' – a technology that 'extends the life of oil fields', breathing a couple of decades of vitality into reserves that would otherwise have to be considered depleted.[51] (One study of a Canadian oilfield showed that this new lease on life could extend up to eighty-four years.)[52] It was a sibling of fracking, with its brightest future ahead of it. In a necrology for peak oil published in 2014, the *Wall Street Journal* pointed to the innovation coming up next: 'When rocks are fracked, a large amount of oil remains left behind. Fracking tends to free the lighter, smaller gas and oil

molecules but leaves behind heavier and stickier molecules. One idea calls for using carbon dioxide to flood into the tight rocks and push oil out ahead of it.'[53] Where might CO_2 for this purpose be found?

To begin with, supplies for enhanced oil recovery were located in natural stores: subsurface cavities holding CO_2, much like the volcanic Lake Nyos in Cameroon. Wells in the Permian Basin were fed from domes scattered across the region. In 2010, at the beginning of the great American oil boom, the Energy Information Administration looked forward to decades of rising output curves, with the help of enhanced oil recovery: by 2035, this technology would be involved in 37 per cent of onshore production, up from a couple of percentage points.[54] 'To pick up the pace, you have to step on the gas: carbon dioxide, that is,' ran an advertisement from Kinder Morgan.[55] But one barrier threatened to close this way to further acceleration. While production by means of CO_2 flooding 'has steadily increased, its growth has slowed in the past few years', noted the *Oil and Gas Journal* in 2014, and 'this is due primarily to limits on accessible, affordable supplies of CO_2.' The price was on the up. 'Natural CO_2 resources are limited', lamented this house organ of the industry, and so future expansion would have to rely on 'new sources of industrial CO_2.'[56] The first that came to mind were CCS installations: the gas could be led away from smokestacks and sold to oil companies and injected into wells to get more out of them.[57] But even more fortunately, there was now also a bottomless source in the air itself. From this set of circumstances emerged the idea of using direct air capture for enhanced oil recovery.

When CO_2 squeezes out the oil, it moves into the vacated hideouts and stays there. The gas is sequestered underground. Chevron did not invent this technique for the purposes of removal, but in the 2010s, some came to view it through that lens. Why not let oil companies draw down CO_2 into their ageing fields? One such company raised this banner with greater fervour than anyone else, namely Occidental, a top operator in the Permian Basin, the seventh largest oil corporation in the US; another, if slightly smaller, money-making machine and aggressive output accelerator.[58] In fact, it was uniquely aggressive: as of 2022, no other company in the world had expansion plans so far outside the envelope for 2°C.[59] And none was more excited about DAC. Occidental – or Oxy, for a moniker – appointed the first

female CEO of an American oil major, Vicky Hollub, the lone woman in an utterly male-dominated realm. Hollub became the bannerwoman of DAC. 'Back in 2011', she recounted, 'we did a review of our oil and gas assets. We realised we didn't have access to enough CO_2 to fully develop the oil reservoirs we had. Using anthropogenic sources of CO_2 was one way in which we could continue generating incremental oil production' – DAC as a solution to the conundrum of natural limits.[60] With a conduit from atmosphere to lithosphere, nothing could prevent Oxy from scavenging any remaining drops. 'The last barrel of oil that's produced in this world should be from CO_2-enhanced oil recovery,' proclaimed Hollub, and *après moi, le déluge*.[61]

Oxy would not be satisfied with carbon neutral oil. When Lundin announced that stunt, it was primarily based on the use of renewable electricity in drilling operations, supplemented with a bit of tree planting in Ghana. Oxy aimed higher. 'We estimate', a company representative told the US Senate in 2019, that DAC would enable the production of the first 'carbon negative barrel of oil.' Because CO_2 from the atmospheric surplus is drained into the ground, the oil that comes up will not add to but subtract from the total amount. Burning it will be a way to bury carbon. 'We think this is an example of American innovation at its best.'[62] Hollub also made the visionary case for DAC as life-saving force: it ensures that 'fossil fuels have a role in the energy portfolio of the world long term.'[63] Or, 'we believe that our direct capture technology is going to be the technology that helps to preserve our industry over time'. Or, 'this gives our industry a license to continue to operate for the 60, 70, 80 years that I think it's [*sic*] going to be very much needed.'[64] Or, in the most ideal of futures, there will simply be 'no reason not to produce oil and gas forever'.[65]

Oxy teamed up with Carbon Engineering, and together they formed 1PointFive – the name of the limit to global warming laid down by the Paris Agreement, now also a venture for oil recovery sans limits.[66] 'Today we see the birth of a new species,' trumpeted one representative when spades were put into the barren land of Notrees, Texas.[67] Notrees? The town was so called because when Shell established a gas plant there, it cut down the one and only tree in the area.[68] Now a new species was born, in the form of structures rising under the name of Stratos – 'a nod to the natural systems

the project seeks to protect and restore'.[69] 1PointFive building Stratos in Notrees: it would be nothing short of the largest DAC plant on Earth. It would capture half a million tonnes per year.[70] That would be upwards of ten times more than Mammoth could do.[71] Construction was scheduled to be completed by 2025, and then 1PointFive – so it said – would build 100 additional similar complexes around the world in the decade to come.[72] Texas would be a prime location.[73] To bankroll Stratos, Occidental drew on the formidable resources of BlackRock – more than half a billion dollars were pumped into the project, a sum that made most other investments in removal pale in comparison.[74] Perhaps no longer a Fata Morgana, capital was on the move towards DAC.

Did this in any way compromise or corrupt DAC in general and Carbon Engineering in particular? David Keith founded his company with capital from Murray Edwards, a baron of the Canadian tar sands.[75] Along the way to Stratos, it received money from Chevron, as we have seen, as well as coal giant BHP.[76] It was never negative about fossil fuels. When we interviewed CEO Steve Oldham (who later cruised over to Captura), he argued that it was 'wishful thinking to believe we can instantly eliminate fossil fuels, across the planet'; hence we need to 'be pragmatic', which involves acknowledging that 'removal of CO_2 from the atmosphere is just as good, if not better, than stopping an emission'.[77] Removal would be particularly good if it could drive up some oil in the process. In a testimony to the senate, Oldham explained that Carbon Engineering went for the largest scale in the DAC hierarchy – the monster truck design – because that was how it could best supply companies interested in enhanced oil recovery.[78] The reasoning evidently appealed to investors, one of whom told *Forbes* that 'right-leaning investors and politicians like the fact that Carbon Engineering uses technology to enable the continued use of oil'.[79] The enabling had one strictly technical and one broadly ideological dimension, the two fused in harmony. It was thus a kind of homecoming when Carbon Engineering was bought by Oxy in late 2023. Keith and the other previous owners got to share more than $1 billion for it.[80] Such was the dawn of the brave new world of DAC.

At this point in our story, it might be worth clarifying that the notion of carbon-negative oil has no relation to reality other than as a negation: there is no way that DAC can remove CO_2 if it is coupled to enhanced oil

recovery. In every physical world, it adds to the excess. Suppositions about a removal effect conveniently forget – if that is the right word – the CO_2 emitted from the oil pushed up for combustion.[81] For any such effect to occur, the amount of gas trapped underground would have to be larger than the amount released when the oil is put on fire, and when it is refined, and when it is transported, and when it is drilled, and when the CO_2 is injected, and when the DAC plants operate, all put together: but this is not possible.[82] The aggregate CO_2 set free at the end of the cycle is typically four to five times larger than what is detained.[83] Only if the injection were more than five times larger than that required per extracted barrel would the effect kick in; but then the operation would mostly cease to be enhanced oil recovery – it would be sequestration full stop. Oxy intended to connect Stratos to its oilfields in the vicinity. This, after all, was why the company was originally taken with DAC. By far the largest physical instantiation of this emerging technology, as of the mid-2020s, was thus *engineered to recycle carbon molecules so as to put even more of them in the atmosphere*.[84]

Put differently, the negative emissions technology widely regarded as one of the most promising was about to flip into a positive emissions technology – not (only) because of some hazy mental picture but because of the hands-on material mechanisms of these facilities. Enhanced oil recovery already dominated CCS. Nearly all CO_2 captured through such filters in the US was conveyed into wells; nearly all CO_2 pipelines operated for that purpose (including those that ruptured).[85] Apart from that one BECCS plant in Illinois, there were also four smaller ethanol-production plants that piped their captured gas to oilfields.[86] A network of fresh pipelines was slated to connect another fifty such plants to the sagging Bakken formation.[87] Enhanced oil recovery was thereby well positioned to swallow BECCS. Would it do the same with DAC? The one company that long resisted this scenario and abjured affairs with oil companies and considered it a point d'honneur to refuse money from fossil fuels was Climeworks, born not in the lap of ExxonMobil or the tar sands but in neutral, urbane Switzerland. Yet when Climeworks entered the American market and prepared for the next jumps in scale, it lost its inhibitions. The Swiss entered agreements with California Resources Corporation – an oil and gas firm long engaged

in enhanced recovery – as well as Gulf Coast Sequestration, whose investments spanned gas projects around the world.[88] And with that, the last startup in the original triumvirate appeared to have gone over to the dark side.

Sewage in the base

Outside the US, the dominant classes in one key region knew which way the wind was blowing: the Gulf. Occidental had tentacles in the Orient, not the least in ADNOC, the national oil and gas company of the United Arab Emirates.[89] ADNOC was trying to beef up its capacity for enhanced oil recovery, and it turned to Occidental for advice.[90] Occidental taught it about DAC. In October 2023, the two announced a deal, under which the Emiratis would invest in the plants of the Americans – Stratos and its coming satellites – and the latter build de novo for the former.[91] Less than two months later, the CEO of ADNOC, Sultan Al Jaber, took the stage as the president of COP28 – the man, that is, charged with leading that year's round of talks about how to deal with the climate crisis. He did not miss the opportunity to press for negative emissions technologies. 'Renewable energies are not and cannot be the only answer,' he asseverated.[92] 'It's not me who is saying this, it is the scientists and responsible intergovernmental agencies … and also the facts on the ground.' On the link between fossil fuels and CO_2, he took a by now familiar line: 'Are we after decarbonisation, or are we after some ideological idea against oil and gas? We are after emissions, so let's stay focused on that, that is our enemy; let's fight that, let's not fight an industry that has helped shape the world we are all in today.'[93] 'At the end of the day, you need to keep the air conditioning working,' another UAE official helpfully added.[94]

Closer to home, there was Oman. Already in the very first paper on DAC, Lackner had pointed to the unassuming sultanate as an Eldorado awaiting its rush.[95] A type of scraggy, coarse rock by the name of peridotite abundant in the country would be particularly amenable to sucking up and holding CO_2 in rock form.[96] There was an Omani startup called 44.01 with a clear-cut slogan – 'We eliminate CO_2' – eyeing the massifs, and soon after

COP28, ADNOC announced a joint venture with it.[97] CO_2 would be captured and sunk into peridotite mountains stretching into one of the emirates. Marketed as the first step towards 'mineralising billions of tons of captured CO_2 across the region', this was not just another exercise in enhanced oil recovery but an attempt at fully fledged carbonation.[98] Yet it ran alongside the mandatory expansion. ADNOC had its own five-year plan for an 'accelerated growth strategy', by one count the fifth most assertive in the world; at its centre stood the Upper Zakum field, where the company prepared for a new generation of fixed capital. It involved 'the construction of four artificial islands in shallow water [which] can accommodate 450 wells, 90 platforms, as well as drilling rigs' and so on.[99] Whatever could be actually mineralised up in the mountains, it would likely be but drops from this bucket.[100]

Over in Qatar, the state sought to move into 'the spotlight as a country that takes climate change seriously' by transforming air conditioning systems into DAC apparatuses, with the assistance of its largest foreign investor, Qatar Shell.[101] And then there was Saudi Aramco, the titan towering above all others. It planted mangroves on the sandy shorelines of the Kingdom. It spoke fondly of the species *Avicennia marina*, with its 'upward-pointing emerald green leaves', the spreading of which was part of the company's 'ongoing commitment toward turning the tide on climate change'.[102] One investigation suggested that if all the mangroves advertised by Aramco were to last until 2060 – if they do not die in the heat and rising seas, that is – they would indeed capture a quantum of CO_2. But the fossil fuels produced by this same company will generate a quantum 12,000 times greater (assuming output stays at the level of 2019).[103] The Kingdom was the living soul behind the Middle East Green Initiative. Here the goal was to plant 50 billion trees across the region.[104] The Kingdom took an interest in the ideas of Lackner, and it pioneered the development of 'mobile DAC' – filters for cars and trucks that capture (some of) their CO_2, a hybrid between DAC and CCS that would cleanse internal combustion engines of (some) emissions.[105] Aramco invested in Global Thermostat, and then Captura, and then CarbonCapture, and then Spiritus, and then it partnered up with Siemens to develop a first DAC facility inside the Kingdom itself.[106]

Air capture looked like it was coming to Arabia. This coincided in time with a combative counter-campaign against any talk of transition, an almost bellicose defence of fossil fuels: ‘We should abandon the fantasy of phasing out oil and gas, and instead invest in them adequately,’ thundered Amin Nasser, CEO of Aramco, to the Houston conference for oil bosses in early 2024; the audience applauded.[107] ‘In fact, in the real world, the current transition strategy is visibly failing on most fronts,’ he went on, denigrating solar and wind as useless. ‘And, despite our starring role in global prosperity, our industry is painted as transition’s arch-enemy’; loud wailing.[108] He was back the year after, developing his oratory with the contention that ‘there is more chance of Elvis speaking next than the current [transition] plan working.’ By now, Nasser no longer felt himself a victim of defamation. ‘We can all feel the winds of history in our industry’s sails again,’ he told the audience in early 2025.[109] Presumably this referred to the political winds from the second Trump term; but the winds of pecuniary fortune had, of course, been filling those sails for years.

In 2022, Nasser’s company made an annual profit likely to have been the largest for a corporate entity in the entire history of the capitalist mode of production.[110] And then the next year yielded the second largest profit ever for Aramco.[111] These giga-profits were, as a matter of course, reinvested in expanded reproduction; among the initiatives was a programme encouraging the spread of petroleum-powered cars and buses and planes and ships in sub-Saharan Africa, so as to ensure a growing market.[112] It was in this context that Aramco made its moves on DAC. Sewage ideology was coming home to the base.

Of theatre and prepping

Why did they do this? Why did oil and gas companies bother with removal? What made them pay lip service to and also some money for the pursuit of drawing down CO_2 – primarily by means of DAC, their new darling (by 2023, more than half of the oil majors had some investment in it)?[113] The predilection for enhanced oil recovery requires little explanation. Albeit a tortuous way to get at the needed gas, sourcing it from a saturated sky would ensure infinite supply. If it adds decades – perhaps close to a century

– of continued extraction from existing fields, the gains would be splendorous. An entire human lifetime of accumulation could be pressed out of wells that had already had their initial investments recuperated. There was a prosaic business case here, particularly if politicians were willing to throw subsidies at it, and if costs looked like they would come down, and if alternative sources of the gas were drying up. Primitive fossil capital just did what it always does.

But this still left plenty of instances where no oil recovery was involved. What did the companies stand to gain from engaging in any such removal? Without further ado, we can cross out the hypothesis that they did it to save the planet. The scientific literature was unanimous about the facts that *all* companies in this circuit were busy expanding their production of fossil fuels, that *none* spent any meaningful sums on renewable energy – no oil major allocated more than 0.1 per cent of revenues to it – and that, overall, signs of their decarbonisation amounted to less than zero.[114] Whatever they did do, they did to 'advance their commercial interests' – to maximise their profit-making capacity, that is.[115] Mitigation means abolition of that capacity. If it needs to happen quickly, because the task has been left undone for too long, there will have to be a swift and remorseless liquidation; and so we can expect primitive fossil capital to fight harder for its existence the later the hour, insofar as the task is still in the air.[116] The embrace of removal should be viewed against this background. It could be denounced as 'greenwashing' – a populist slur that, justified as it is, does not, however, have much analytical depth and does not say a lot about what is going on here.[117]

Primitive fossil capital has resisted the reality of the climate crisis from the moment it appeared on the radar. ExxonMobil and Saudi Arabia, to mention just two instances, were among the most pig-headed enemies of the very idea that something needed to be done.[118] Once actors like these had slunk away from literal denial, they began to champion various 'techno-fixes' or some technological arrangement that would allow them to maintain their 'long-established practices' – notably CCS projects such as Gorgon (in which ExxonMobil was a partner) and fossil gas (an early putative bridge to a cleaner world).[119] The overshoot conjuncture is the realisation of this desire for continuation and extension of the self. The *mégabassine* paradigm of climate politics, in which techno-fixes proliferate

on every front, sprawls out from this decades-old posture and pursuit and sinks deeper into the ground as the defensive endeavours intensify.

At the centre is the redoubled resistance against reality: the reality of an absolute contradiction between the existing set of productive forces and the existing climate on Earth. We tend to think of technology as close to or even at one with material reality. It engages with the nuts and bolts of the physical universe. But the logic of late climate technology, as championed by primitive fossil capital, is rather *escape from reality*, since the essential attraction of all this tech is the semblance of a consonance between fossil fuels and climate stability, when none can exist. At some level of their minds, the human subjects in question are aware of the reality – such is the nature of all resistance against it – but they resolve to buy and sell a fantasy.[120] It can take any number of shapes. Investors can open the catalogue and browse. 'Constant change is the best way to conceal the old untruth,' in the words of Adorno; and untruth is indeed the odourless gas that fills every pore of this sphere.[121] Consider what is going on in the following sentence: 'We continue [to] explore for oil and gas to meet the global demand for energy and support the transition to a low-carbon future,' signed Equinor.[122] So much untruth of this kind is being pumped out as to eventually produce the effect of gaslighting.

A material contradiction between fossil capital and the climate system has generated a type of technological development in which psyche and ideology have primacy over materiality. From the standpoint of the companies, it has a lot to do with reputation. They need to be reputable to get customers and investors.[123] Hence they engage in 'impression management' or 'certification of virtue' – *hasbara*, one might also say – by producing some combination of images and words, as in theatre.[124] Much of this happens through advertisement. During the years of partnership, the real value of Global Thermostat lay in its utility for ExxonMobil ads and commercials. Oil and gas companies typically do not disclose the size of their investments, but we can assume that their appearance in communications materials is out of proportion to the sums involved. Large databases have yielded a high ratio of green messages relative to any substances; indeed, the companies have been found to spend as much on the former as on lobbying efforts *against* climate measures.[125] One does not have to be a critical researcher to pick up the logic. 'The rationale for

supporting climate initiatives outwardly while flouting them in practice was perhaps best summed up by a banker who said the quiet part out loud to his peers at a conference in 2021 in Houston. “Do what you can to inoculate yourself,”’ *Fortune* quoted an energy banker in Texas. ‘Put another way, claiming to be clean with enough conviction may be enough to appease your critics while you continue earning money from dirty fuels.’[126] What critics, though?

The final and conclusive turn from literal denial to other forms of resistance against reality, including the removal fix, appears to have taken place in the mid-2010s.[127] Several things occurred at this moment in time. The Paris Agreement handed over climate governance to voluntary, private initiative; negative emissions technologies came to the fore; for a brief moment, the climate movement succeeded in pushing its issue high on the agenda; perhaps most importantly, a discourse formed around stranded assets.[128] It was the latter that generalised the crisis of reputation.[129] Chevron made as much clear: ‘Community divestment initiatives may lead to increased negative investor sentiment toward Chevron and our industry and to the diversion of investment to other industries.’[130] Companies like this one might have had a bad name among (parts of) the public for a long time; what was new was the critical gaze from investors. Were assets safe from the risk of stranding? Fossil fuel producers needed to patch up their reputation vis-à-vis prospective injectors of capital. A prime strategy became the demonstration of a portfolio of holdings in negative emissions technologies, if only in potentia.[131] CCS installations promised to inoculate the pieces of fixed capital on which they sat. A coal plant with a filter on the smokestack would presumably not be in danger from emissions cuts. But with the turn to removal, companies could make a far bolder claim: our *entire business enterprise* is cleaning up the atmosphere. DAC did not put a halo on an individual chimney, but on the company as a comprehensive whole, precisely because it targeted ambient air (and the same went for the other technologies). The logic of investing in DAC was here twofold: to signal to governments, lest they get any ideas, that our company is part of the solution and to thereby signal to investors that our assets are safe from stranding. This could all be done in the register of theatre. Capital destruction did not yet exist as more than a spectral threat; conversely, negative emissions technologies were crucifixes for chasing it away.

But what if an episode of asset stranding actually *were* to take place? What if states mustered the resolve to start sealing wells? Then a parallel infrastructure under development might help to keep them open; pilot projects and symbolic investments could be scaled up in a hurry.[132] We might think of them as the business equivalent to prepping. Apocalyptic capital destruction has evidently not happened and may not loom in the visible future, but it *might yet come at some point*. To go about business-as-usual in the living quarters and exude confidence, it can be useful to have a few cans of DAC in the cellar, for the day when survival might be at stake: a matter of hedging. Companies investing in removal were hedging against possible futures, as capitalist enterprises are wont to do.[133] The investment climate tends to be uncertain, and never more so – if your company digs fossil fuels – than in times of climate breakdown. Giants from ExxonMobil to Saudi Aramco and lesser entities in between realised a dictum from Lackner: negative emissions technologies 'provide insurance against the possibility that political pressures or actual climate changes would force a drastic reduction in carbon dioxide emissions'.[134] At the moment of taking out the insurance policy, the quantities of removed CO_2 could be minuscule: the point was to project the ability to increase them. A maverick scholar, Lackner might have been the incarnation of passive capital protection. What the companies did was eminently *active capital protection* – proactive, pre-emptive, meant to forestall the storm or, should worse come to worst, weather it.

No advanced critical faculties were, again, required to discern the strategy. 'The oilmen's critics allege that their enthusiasm for carbon removal is mainly about improving their reputations in the eyes of increasingly climate-conscious consumers, while pumping more crude for longer. There is surely some truth to this,' admitted the *Economist* (but true to its class constituency, it nevertheless welcomed the enthusiasm of the 'oilmen').[135] 'Greenwashing is a risk. Environmentalists are right to worry. Big oil will try to use carbon removal to defend the status quo,' conceded no less an insider than David Keith, writing in the same magazine, fresh from his juicy deal with Oxy. 'In a decarbonising world in which big oil only does oil and gas, its only future is extinction and it will fight progress with its back to the wall.'[136] It will thereby also open another front of climate politics when it's too late.

Late value form

There is not enough planet Earth to first turn it inside out and then turn it outside in again. Available resources do not allow for removal of the total aggregate of CO_2 from the fossil fuels in stock. Instead, removal should, for all the reasons we examined in the appendix of caveats, be conceived as a restricted practice, hemmed in on all sides by limitations – of energy, of land, of subsurface storage sites, of everything needed to get underway – more in the nature of advanced surgery than basic hygiene. A question then arises: what are we going to use it for?[137] To what end should the precious removal capacity be deployed? If negative emissions technologies can indeed attain consequential scale, should they be pressed into the service of life extension for fossil capital? Although they may serve that purpose already, even before they have entered the material world, the imminent risk is that, upon actual entry, they will be corralled into business-as-usual, as in DAC plants for enhanced oil recovery. Removal will then be negated into its opposite. This would be in accordance with the universal law of capital devouring everything potentially good and excreting it as something actually bad. Here the most egregious instance might be the use of removal to re-animate fossil fuel companies in general and enhanced oil recovery in particular, but there is something broader at work, which we might call *late value form*. In the overshoot conjuncture, *capital seeks to press negative emissions technologies into the production of exchange-value. Against it stands any interest in deploying them for the use-value of reversal*.

Here, then, is a second axis of contestation around negative emissions technologies: intersecting with late technopower is late value form. A concrete example would be communities protesting against projects for enhanced oil recovery. In Texas, Elida Castillo, a Latino environmental justice activist and community organiser, voiced dismay over the arrival of a DAC plant in her neighbourhood: she and other residents were ‘worried about the dangers of storing CO_2 where they live, the risk of new pipelines being built, and whether DAC is a good use of money in the first place. And there’s reason for distrust. After all, the DAC plant belongs to Occidental’: “‘You’re pretty much entrusting the bank robbers to guard the safe,” Castillo said.’[138] Popular opposition focused on those projects *both*

endangering their resources *and* enriching the very companies that fan the flames of heating.

But the state apparatus was of a different mind. Secretary of Energy Jennifer Granholm praised Oxy for 'exactly the kind of bold thinking we need more of'.[139] Her own thinking and that of Hollub – the secretary, the CEO – were in convergence. Months after the former took up her position under Biden, she asserted that 'traditional fossil energy is going to remain important, even as we work to reduce carbon emissions'; echoing Nordhaus, 'we're also putting our brain power at the Department of Energy and our financial resources to work' on 'approaches like direct air capture'.[140] ('We need to extend the life of oil production', maintained Hollub, because it 'makes the world a better place'.[141]) For its boldness, Oxy was awarded one of two major government grants for developing a 'DAC hub', in Texan oil country (the other went to Climeworks and Heirloom).[142] The cheque was for $500 million.[143] The state also offered companies a tax credit, known as 45Q, for every tonne of CO_2 they grabbed hold of. For every tonne, that is, they could apply for relief from tax payment, a form of indirect reward to (supposedly) green activities much favoured by the American state.[144] Under the first edition of Trump, companies would receive $50 per tonne captured through DAC, even when it was utilised for enhanced oil recovery. Biden then raised this handout to $130.[145] The 'Office of Fossil Energy' under Granholm's department was renamed the 'Office of Fossil Energy and *Carbon Management*', its mission redefined as 'research, development, demonstration, and deployment *to minimize the environmental and climate impacts* of fossil fuel and industrial processes' – sewage as state ideology.[146] This office celebrated an annual 'Carbon Management Day', as if to give the highest imprimatur to the ideas of a Lackner or a Keith.[147] Support for late value form became a pillar of the climate politics of the Biden administration.

Meanwhile, the US 'produces more crude oil than any country, ever', the same state apparatus proudly announced, the curve steadily rising under Biden, new records forecast – for oil *and* gas – in 2024 and 2025, no end in sight.[148] With the various boons, his administration might have also created the condition for a boom in enhanced oil recovery, similar to the earlier one in fracking. Possibly of even greater moment, it locked the development of DAC technology into late value form. 'These hubs are going to help us

prove out the potential of this game-changing technology so that others can follow in their footsteps,' exulted Granholm; they would 'position the United States as the location to demonstrate the commercial viability of direct-air capture', concurred Hollub.[149] The programme was explicitly conceived to help midwife DAC in the US *and the rest of the world*. If successful, this productive force – supposed to be restorative, in at least some visions – would grow up in symbiosis with primitive fossil capital.[150] Client states of the hegemon, such as the UAE and Saudi Arabia, readied themselves to assist in the upbringing.

How would this nestling fare under the second Trump? In early 2025, no one could say with any certainty; consistency and predictability were not among the primary qualities of this president. Employees at the Office of Fossil Energy and Carbon Management responsible for removal were laid off and payments to DAC hubs frozen – not necessarily because of any Trumpian antagonism towards these technologies as such, but because of the way he and Musk set their wrecking balls working on the state apparatus.[151] This could hollow out support mechanisms. But Hollub, for one, was not losing any sleep over it. If DAC could provide the lubricant to keep the country's oil wells productive a good while longer, then even the 2025 version of Trump should love it – indeed all the more so. It would help him get that liquid gold from under his feet. 'President Trump knows the business case for this. I've had several conversations with him,' Hollub assured a group of slightly jittery investors.[152] In fact, 'I think the election of Donald Trump to become our next president is going to be very positive for our industry, especially for our direct air capture.'[153] Perhaps it would do some good for BECCS too. Trump's secretary of the interior was Doug Burgum, previously the governor of North Dakota. He was 'obsessive about carbon capture' and 'the technology's chief evangelist' in that state.[154] Burgum was a staunch advocate of the Midwest Carbon Express, the misunderstood CO_2 pipeline. He thought it offered beguiling economic opportunities, not least because the substance it carried could bring new life to North Dakota's ageing fields of shale oil.[155] Nothing could be more indicative of the nature and power of late value form than the prospect that even the most unashamedly denialist administration might jump onto its bandwagon.

But late value form extended far beyond such cartoonishly ghoulish companies as Oxy and Exxon and Aramco. No less prominent was the later crop of digital enterprises with an enlightened mien: Microsoft, Amazon, Google, Meta, Shopify. How did they inject removal into their veins? Through offsetting, of course. This practice had its own history, another tributary to the overshoot conjuncture that weighed heavily on its future course. Indeed, the currents and sheer force running through this stream might well sweep up the technologies launched in the 2020s, because it had already done so several times before. Approaching 1.5°C could seem like a moment without precedent. But the world had ended up there by passing through an unbroken series of decisions *not* to cut emissions and to do something else instead; and this practice had become so habitual and systemic as to threaten to determine the next phase too.

A brief history of offsetting

Offsetting came into the world in the 1980s. This, of course, was the Sturm und Drang period of neoliberalism, when anything that seemed to regulate and limit market imperatives was a target of furious assault. Environmental protection came under some of the fire, and economists exerted the most creative sides of their brains to produce an alternative method for addressing the destruction of nature. It had to be the market imperative that could execute it. A seminal document from the end of the decade, authored by market lover Robert Stavins and colleagues, outlined the reasoning. Titled ‘Project 88 – Harnessing Market Forces to Protect Our Environment: Initiatives for the New President’, it sought to convince the incoming George Bush the Elder of the need for some ‘new thinking’.[156] The authors considered it ‘less and less likely that we can increase environmental protection simply by spending more money’; society needed to accomplish this noble goal without allocating any special resources to it or otherwise disturbing the existing streams of exchange-value. ‘The approach that seems most promising’ is ‘one of harnessing market forces’. This invisible hand could kill any number of birds with one stone – selecting the optimum measures for protecting the environment, picking out the cheapest options, driving up ambitions, solving all manner of other problems along the

way.[157] The idea flowed organically from a decades-long assault on the merits of conventional regulation, which by comparison was brutish, expensive, inefficient.[158] What, then, could the market do for climate?

Project 88 stated that 'no priority is higher than slowing the accumulation of greenhouses gases' – no priority is higher. To this end, it favoured 'a system of international emissions trading', whose chief merit would be to create 'incentives for efficient GHG management', the latter being a keyword.[159] Insofar as they had broken with literal denial, many bourgeois economists at this point recognised that something in fact needed to be done. Yet they regarded fossil fuels and their emissions as a fait accompli. How could these positions be reconciled? A focus on management pointed to the possibility of keeping the sources of the problem open and active, while closing down something else – or, having the former 'compensated' for. Here was the principle of offsetting in a nutshell: let emission A happen, but counterbalance it by some equivalent quantity of non-A. Best part of it, these latter quantities could be traded in the form of credits. An actor who wants to conduct emission +A could purchase –A from a seller delivering the service. The new owner of –A would then rightfully count the counterbalancing activity as belonging to the self. True to the times, Project 88 envisioned 'forests as "carbon reservoirs" to generate valuable credits'; 'investments in tree plantations with forest product firms' could also be used.[160] We here once more encounter the notion of negative emissions technologies *avant la lettre*, decades before overshoot.

This all seemed to make eminent economic sense. Rather than having exchange-value destroyed, it would be left untouched and attached to a second mechanism for creating exchange-value – credits fetching a price on a market – that would rub out the climate impacts of the first. A constant refrain followed: the atmosphere does not care where CO_2 is taken out. One tonne from Guatemala has the exact same effect as one tonne from the US. If it is cheaper to avoid the former emission than the latter, simple economics dictate that this be done. Offsetting thereby liberated the most valuable fixed capital from the onus of excising emissions; instead, it would balance out their plus by linking them up with the cheapest forms of minus on the other side of the planet if the marketplace dictated as much.

Project 88 recommended a green light for new facilities emitting CO_2. They would just have to buy credits to expiate themselves. With this, the

ideas of Dyson and Nordhaus were coming closer to reality; in the same year of 1988, an electric utility in the US with the uninspiring name 'Applied Energy Services', or AES, first put them into effect. It had new coal plants on the table but became apprehensive about the fuss over the greenhouse effect and distraught by the contribution that poured from its chimneys. AES decided that 'it was time to stop talking and act'.[161] The act in question would not involve leaving the coal seams untapped: that was unconscionable. 'Since coal is such a large and potentially cost-effective energy resource', the company reasoned, 'it would be highly desirable and pragmatic to preserve coal as an option in future energy policies that address the global warming challenge.'[162] And so it started looking around for some other solution, and soon found that 'trees provided the most practical and cost-effective way to solve AES's CO_2 problem', for trees could indeed 'preserve coal and gas as fuel options while mitigating any adverse global climate change effects they might have'.[163] A quick calculation showed that 500 to 2,000 square kilometres covered in trees should do the trick. Where to put them?

The World Resources Institute, the embodiment of a big green NGO, agreed to lend the utility a helping hand.[164] It issued a call for proposals, and from the responses that came back in the mail identified the most promising ones. A project in Guatemala was paired with a new coal plant on the banks of the river Thames, just outside New London, Connecticut, US, to be operated by AES.[165] Through hands organised by the local branch of CARE, a humanitarian NGO, the American company would plant 52 million trees on Guatemalan soil, supposedly enough to mop up the entire 15 million tonnes of CO_2 that the New London plant was scheduled to emit over its expected lifetime of four decades. In return, CARE and its battalion of largely voluntary workers would receive $2 million, or less than 0.14 dollars per tonne of CO_2 – a bargain.[166] Thus was born the world's first carbon offset project.

On the other side of the Atlantic, five electricity companies in the Netherlands were more than a little intrigued. By 1990, they had joined together in the Face Foundation – 'Face' for 'Forests Absorbing Carbon-dioxide Emissions'. The ambition, and one can here be forgiven for a sense of *déjà vu*, was to allow for the building of a new coal plant in the Netherlands 'with no net emissions to the global atmosphere'.[167] Face

calculated that 150,000 hectares of trees would suffice to generate the requisite offsets, but since the Netherlands had no such space readily available – no one would roll a forest carpet over The Hague or the port of Rotterdam – it would have to come from elsewhere, the generality of it from land in Ecuador, Uganda and Malaysia.[168] AES may have been first, but Face, with the world's largest offsetting programme, as counted in the number of countries involved, quickly overtook it.[169] If this was removal *avant la lettre*, the identity of its parents was telling. It was born of coal power utilities *seeking to build new plants in the face of climate concerns*. Politics in the long heat often has the appearance of the eternal recurrence of the same, under the guise of faux novelty.

At this moment in history, the idea of sinks and offsets enchanted centrally placed institutions. The US Environmental Protection Agency converted to it in the early 1990s. The IPCC warmed to it as well.[170] Both had been sceptical at first, but reservations fell away like outmoded prejudices; eyes opened to the bright neoliberal light. When the UNFCCC was signed in 1992, a primordial form of offsetting was included as one option on the menu.[171] Before the very first COP, an official from the US Department of Energy volunteered that 'tree planting will allow the US energy policy to go on with business as usual out to 2015' (not, we now know, a fixed end date).[172] Another torchbearer of neoliberalism, New Zealand, envisaged that it could do four fifths of whatever it needed to do for the climate by counting the work done by forests, supplemented with one fifth of actual emissions cuts.[173] In the heated run-up to Kyoto – the by now half-forgotten COP that marked a milestone for two decades of climate politics – a coalition including the US, New Zealand, Canada and Australia (lest any Anglo-American settler-colonial state be left out), pushed hard for the widest possible latitude for offsetting. If a rich country preferred to pay someone poor not to emit CO_2, it should be free to do so and take credit for it. Or, it should be able to count its own standing forests as sinks that performed compensatory work.[174] The EU opposed these advances, until it too – under pressure from its own forest carpets Sweden and Finland – made a volte-face. Offsetting became the cornerstone of the Kyoto architecture. The Protocol was endowed with its own official carbon offset market, known as 'the Clean Development Mechanism'.[175] It was this market of which Graciela Chichilnisky claimed to be the chief architect.[176]

There were, of course, detractors as well. They argued that all the fluff around sinks and credits and offsets was nothing more than a poorly disguised attempt by the US and its allies to 'cheat' the rest of the world out of the emissions cuts they, by any reasonable standards, ought to shoulder.[177] The low-lying Marshall Islands complained that provisions for using forests 'tend to delay early action to tackle emissions at source'.[178] A nascent climate movement joyfully ripped apart the inequities and absurdities of offsetting.[179] In London, activists set up Cheat Neutral and offered to neutralise infidelity: if someone cheated on a partner, a handful of dollars could be paid to the company, which would invest them in the faithful or celibate lifestyle of others, so as to level out the total amount of heartbreak.[180] Did it not sound commonsensical? But the critique was the proverbial water off the duck's back: with Kyoto, the UN itself had authorised the creation of a carbon market. Nothing could stop it now. Just a few months after the Clean Development Mechanism was clinched, BP joined forces with two utilities in the US and announced an expansion of forests in Bolivia as a batch of credits.[181] Tesco launched a scheme for drivers to buy offsets for every tank they filled – a coin that could be minted and reminted over and over again in the coming decades, much as for, perhaps more famously, plane tickets.[182] The rest is indeed history.

Under Kyoto, however, there were still some limits to the practice. In the Protocol, sinks and offsets were inserted only '*after* targets for industrial emission reductions were set' – that is, countries were first told how much CO_2 they must not release, and then they were left to accomplish this as they saw fit, through one flexible mechanism or other.[183] Offsetting remained derivative of the centrally specified cuts. But Paris changed all this. Because it had no mandates or duties or fixed commitments, it opened the floodgates to unrestrained offsetting. The Agreement enjoined countries to achieve a 'balance between anthropogenic emissions by sources and removals by sinks in the second half of this century' – carte blanche for claims of net zero.[184] Removal was now carried away by a torrent of offsetting.

A short story starring Microsoft

By the early 2020s, the removal business was structured by the logic of offsetting through and through. In the Cambrian explosion of technologies, the startups taking them to the market competed for survival by selling credits. Fledgling entrepreneurs fell over each other to position themselves as the vendors of the newest, hottest, most effective, most trustworthy certificates of removed CO_2. Insofar as these were purchased by consumers with an interest in glossing over an actual release of that gas, no net removal would happen: through the transaction, the –A would simply be matched with +A, in a zero-sum game that could not possibly power reversal. It would at best be running to stand still. This lapse into the default of offsetting was not the result of evil design, nor was it a cover-up of the sort pathological sex addicts might engage in. It was the result of a structural imperative, namely the commonplace market imperative: a producer of removal had to sell their product on the market or else go under.[185] Buyers would, by definition, be the source of demand. Only one other scenario could be dimly made out in the distance: governments stepping in and funding removal out of collectively pooled resources, for its own sake.[186] Until that day, the business would have to be mediated through the market and run the risk of descent into late value form.

Consumers entering this marketplace could pick up the catalogue and browse: fancy some credits from Living Carbon and its genetically modified poplars? Or perhaps faeces from Vaulted Deep, seaweed from Running Tide, rocky dust from Lithos, or the latest squishy white balls from Spiritus? Here the most enthusiastic customers often came not from primitive fossil capital but from fossil capital in general – companies not producing but consuming fossil fuels in the process of money-making and wishing, for whatever reason, to even them out with credits. One customer was in a league of its own: Microsoft.

By the early 2020s, the market had been conceptually divided between ‘durable’ removals – the high-end niche, the hard diamonds of the bazaar: CO_2 supposedly stowed away permanently through DAC, BECCS, enhanced weathering, biochar – and those with a reputation for ephemerality, notably trees: the variety store. The market for durables appeared to be booming, from close to zero in 2020 to 134 companies peddling their goods in 2024. On the side of the buyers, as of that year, the market *was* Microsoft: it alone bagged almost two thirds of all credits

sold.[187] The proclivities of this company might have stemmed from its founder Bill Gates, long worried about the state of the world, an early benefactor of the startups – including Carbon Engineering – author of *How to Avoid a Climate Disaster: The Solutions We Have and the Breakthroughs We Need*; to sum up his CV, the late human face of capitalism.[188] He personified all the usual characteristics of overshoot ideology: the transition is bound to be gradual, and it can only ever be incomplete. 'There are no realistic paths to zero that involve abandoning these [fossil] fuels completely,' and so instead, the future we face is one in which 'we will still be producing some emissions, but we'll have some ways to remove the carbon they emit'.[189] Under his spiritual leadership, Microsoft went on a shopping spree.

One mega-purchase followed another. In May 2024, Microsoft publicised the single largest transaction on this market, until that point: a deal with Stockholm Exergi for the delivery of credits from its future BECCS plant. The tech giant would thereby 'obtain legal title to those removals', in its own words (ecocapitalist outlet *GreenBiz* filed the news under the category 'Practical Magic').[190] This followed a mega-purchase from Danish energy company Ørsted, which also promised to operate a BECCS plant in the near future and have the CO_2 shipped to the Northern Lights.[191] Then came a deal with 1PointFive to buy credits from Stratos – the largest sale of DAC credits thus far. Unlike Oxy's other plans for that plant, the CO_2 removed under Microsoft's patronage would be 'securely stored through subsurface saline sequestration and will not be used to produce oil and gas'.[192] Microsoft was a believer. 'We believe that the time for responsibly scaling BECCS is here and look forward to the coming wave of project developments.'[193] 'DAC plays an important role in Microsoft's carbon removal portfolio.'[194] But Microsoft was a promiscuous shopper; it also bought credits from Lithos and, not as durable, forests in countries like India, Brazil, Peru.[195] What for?

In January 2020, on the crest of the wave of popular mobilisations for the climate, Microsoft made a sensational announcement: it would become 'carbon negative' by 2030. After that date, it would remove more CO_2 from the atmosphere than it emitted, to the point – scheduled for 2050 – when there would no longer be any molecules attributable to it. All the company

had emitted since Gates founded it in 1975 would be gone, the full footprint washed away.[196] The communiqué earned a tremendous amount of positive press.[197] Stories included lines such as the following. 'The thing about Microsoft's work that I love, love, love is the investment in climate equity and environmental justice. This has been missing from the corporate dialogue. More companies should take this kind of intersectional lens.'[198] Microsoft claimed to have been 'carbon neutral' since 2012, thanks to its spendthrift purchasing of offsets; now it would raise the bar and go flat-out negative.[199] This was indeed something new under the bourgeois sun. Never before had a company – and not any company: one of the largest capitalist corporations on Earth; by some counts, *the* largest – pledged to undo the totality of the harm it had inflicted on the climate system.[200] It would do so of its own volition, no government interference needed. It was about to set an example for the rest of humanity to follow – maybe all the way back to a pre-capitalist climate.

About midway into the decade that would turn Microsoft negative, a bit of a hiccup was reported. By its own admission, the company's emissions were 29 per cent *higher* four years into the decade than at its start – up nearly by a whopping third, that is.[201] This was not quite the example for humanity, nor the route that led to negativity. Nothing indicated that the removal credits Microsoft was snapping up were enough to cancel out these emissions, let alone surmount them. At the very best, it was now operating within the fourth configuration of continue and ameliorate – at most the credits offset a fraction of the gush. One driver was all the energy and steel needed for the ever-growing data centres, courtesy, in part, of the AI boom. That boom looked like it would largely be powered by newly constructed gas plants.[202] But the problem went beyond the fossil fuels Microsoft burned within its own process of producing profit, and indeed those consumed by individuals using its software.[203] Few clients of this company were as weighty as the fossil fuel companies themselves.

The overshoot conjuncture coincided with a major thrust towards digitalisation, computerisation, automation of oil and gas extraction: and Microsoft was the supplier second to none.[204] In 2020, Barclays published a report lauding the advances of cloud services, AI, machine learning, remote sensing, edge computing and related technologies into the oil and gas fields of the world, speeding up discoveries, optimising the location of wells,

maximising recovery rates, improving throughput in pipelines and so on and so forth: through the digital nostrils, yet another breath of life into primitive fossil capital. It would cut costs and increase production and, summum bonum, raise profits.[205] 'Big Tech has made a big push into the Oil & Gas sector,' noted Barclays, and 'Microsoft has been the most aggressive, saying that Oil & Gas is the #1 growth market for its cloud services'; and true to form, 'Microsoft has become the cloud server of choice for the industry.'[206] A particularly rewarding product was the cloud computing platform Azure. Just as Microsoft prepared to go negative, it entered a series of highly durable deals with ExxonMobil, Chevron, Equinor, Halliburton, Schlumberger, Petrofac and other heavyweights for integrating Azure into their operations.[207] Microsoft went to the Gulf, to an exhibition hosted by ADNOC, and gave its pavilion the theme 'Empowering Oil & Gas with AI'.[208] In the very week when the company made the 'moonshot' announcement about going negative, it took centre stage at an expo on a similar theme hosted by Aramco.[209] Had it changed its mind?

Two years after the announcement, Microsoft confirmed that it would continue to sell its commodities 'for subsurface exploration and extraction of fossil fuels'.[210] In 2023, the chief technical architect at its centre in Houston posted a gushing accolade to the industry – always 'at the forefront of innovation, constantly pushing the boundaries of what's possible' – and now, thanks to his own company, once more 'unlocking previously inaccessible reserves'. 'With Azure, the future of oil and gas exploration and production is brighter than ever.'[211] By this point, some employees were so disgusted by the hypocrisy that they quit their jobs.[212] Microsoft was plainly not about to wash away its own or anyone else's footprint. Indeed, emissions from the fossil fuels it helped bring to the surface were not even counted among those it wished to neutralise and remove.[213] In the material world, this company reinforced the wall blocking every path to climate stabilisation. By selling means of production to primitive fossil capital, Microsoft profited from the tendency of fixed capital to rise in extraction and built up more assets that must not be stranded: for every mega-purchase of Azure sunk into a field, the incentive grew to keep the oil gushing.[214] No BECCS from Stockholm or DAC from Texas could come close to offsetting this propagation of business-as-usual.

But Microsoft might indeed have set the standards for what other tech companies were expected to do, even if they lagged behind. Shopify stood behind the united Frontier. Like most others, it nominally stuck to the principle of first reducing emissions and then adding removal to go the extra mile. Like Microsoft, it was, in fact, rapidly increasing emissions, mainly by encouraging its employees to fly between offices. But Shopify claimed that its bag of removal credits offset all the emissions from delivering commodities on Black Friday.[215] Google was another regular in the malls of removal. It was a heavy consumer of Indian biochar, Brazilian rock dust, bio-oil charms and DAC credits from a new startup called Holocene (time machine as trademark).[216] But it too was riding an AI wave that caused its emissions to curve steeply, by almost 50 per cent since 2019 – in the direction opposite, of course, from reduction.[217] It was happily publishing greenwashing ads by oil and gas companies on its various platforms.[218] Among its prominent cloud computing customers was Saudi Aramco.[219] Alongside Google, there was JPMorgan, which invested in Frontier, and in Climeworks, and in forests; and, in every year after the Paris Agreement save one, it was the bank that poured the most money into fossil fuel projects.[220] Even the emissions intensity of its investments was headed upwards.[221] (‘We are thinking about commercial value, it’s not for philanthropic purposes only that we buy carbon removal. From a reputation perspective, it brings value to our brand. Our customers expect us to do it,’ explained the head of ‘carbon management’ at JPMorgan.)[222] Another proud backer of Frontier was number one consulting firm McKinsey; and it continued to work tightly with clients like ExxonMobil and Aramco and allied with Sultan Al Jaber to temper ambitions at COP28.[223] The same BlackRock that lifted Stratos off the ground was perfectly clear about its intention not to stop investing in fossil fuels, now or in the future.[224]

Then there was Elon Musk, who, with his XPrize Carbon Removal, preened in more stardom and pioneership than most. His uncompromising commitment to removal was plastered in large, capital letters on the website of the Prize: ‘We want teams to build real systems that can make measurable impact at a gigaton level. *Whatever it takes*. Time is of the essence.’[225] In an interview carried out around the time the Prize was announced, he professed his concern that ‘there is some risk of non-linear climate change’ and it would be ‘not wise to take’ that risk.[226] But as part

of his rightward drift, he also told a festival organised by the far-right Brothers of Italy that ‘climate change is exaggerated in the short term’ and ‘we should not demonise oil and gas in the medium term’.[227] In 2024, he shovelled a few hundred million dollars into denialist-in-chief Donald Trump’s second run for president.[228] In a candid chat between the two billionaires – described as ‘the dumbest climate conversation of all time’ – Musk shared with Trump his views on the climate crisis.[229] Now time was no longer of the essence. ‘We don’t need to rush and we don’t need to like, you know, stop farmers from farming or, you know, prevent people from having steaks or basic stuff like that.’ More concerned about peak oil than an overheating planet, Musk went on to explain that CO_2 concentrations would only become a concern around 1,000 ppm, when ‘it actually simply gets uncomfortable to breathe’ and ‘you start getting headaches and nausea’.[230] The bromance continued inside the White House, where Musk and Trump together rolled back whatever little progress the Biden administration had made on climate and then rolled some more. Tangled and twined though it might seem, there was a thread running through this performance. For all his apparent schizophrenia, Musk embodied a key feature of overshoot ideology: there was no inherent contradiction between denying the depth of the climate problem and posing as the über-patron of innovations for removal. The two themes could play a perfect symphony. All one had to do would be to rethink what removals are for (or shake off any post-substitutionist illusions about it).

The black hole of fossil fuels was not, in other words, only expanded by the likes of Oxy. Everything else was affected by its gravitational pull and drawn into the work of dilating it further – even the firms rumoured to be at the farthest remove from the crudity, even negative emissions technologies and the market on which their credits circulated. The ecumenical engagement with removal merely confirmed the integration between primitive fossil capital and every other circuit of accumulation.[231] Vicky Hollub and Bill Gates were bedfellows (as evidenced by their shared interest in Carbon Engineering). From their respective sides, they pulled removal into late value form – which, it is important to repeat, functioned through ideology as much as through processes of production. Gates did not get any directly enhanced oil, like Hollub. But he and Microsoft earned a first-class reputation.

Everything is unavoidable

In these days of net zero, there was an added rationale for removal: some emissions were ‘unavoidable’. Or, they were ‘residual’ or ‘hard to abate’ – however one chose to put it, impossible to do without. To get to zero, they would have to be effaced by negative emissions of the same magnitude. This line of reasoning had the formal seal of approval from the IPCC; indeed, it was one justification for removal in the IAMs.[232] But what, really, was unavoidable? IPCC models typically left a rump of 20 per cent of current emissions in this category, after the rest had been mitigated – one fifth, that is, would have to remain in effect and balanced out by removal (over and above any return assignment). Countries were betting on roughly the same amount in the plans they submitted to the UN; but their assumptions and definitions and interpretations of ‘residual’ were all over the place.[233] The International Energy Agency turned out to be less resigned to the things that exist and capped this class of emissions at 5 per cent.[234] Companies themselves worked with everything from 0 to 80 per cent; Microsoft’s hypothetical decarbonisation pathway appeared to count on close to 50.[235] The extent of the unavoidable seemed to be in the eye of the beholder.[236] In a world overstocked with assets at risk of being stranded, the temptation to classify emissions as ‘unable to be prevented or stayed away from’ – the meaning of ‘unavoidable’, according to the Cambridge Dictionary – seemed plain as a pikestaff. There was something arbitrary about the way this term and its synonyms were bandied about.[237] Unless the category could be brought under control, the excess threatened to self-propagate.

One solution was to reserve the category for a select few sectors: agriculture (think methane from cows or rice paddies), aviation, shipping, cement, petrochemicals – all difficult to disconnect from emissions, on the common view. (We discussed several of these in *Overshoot*.) However great the difficulties, they did not shrink with the common assumption that said sectors would *continue to grow*.[238] This led to the slightly absurd belief that the cumbersome category of unavoidability was itself inexorably growing: not only could the world not help emitting a great deal, it also could not help doing it ever more. Many things were here naturalised at once. Take aviation, for instance. It was the prototypical member of the residual club:

people want to fly; planes run on jet fuels; there are no substitutes at hand; hence these emissions must be accepted – their growth to boot – and treated by means of removal. But consider again Bill Gates. He was a very frequent flyer. He owned a private jet, a Bombardier BD-700 Global Express, complete with a salon of discreetly beige seats. In 2017, he took sixty flights and left a plume of more than 1,600 tonnes of CO_2 in his wake.[239] This gave Gates, from the use of his private jet alone, the same carbon footprint as a small town in Burundi.[240] He did not think this was a problem, because Bill Gates was an avid investor in removal and devotedly offset his sins with credits.[241] He bought them from Climeworks – indeed, he boasted of being its largest individual customer.[242]

On the generally accepted logic of unavoidability, Gates's flying emissions would fall in this inviolable category. This one billionaire would thereby be entitled to a disproportionate share of – remember, by nature limited – removals, simply by virtue of his ability to pay handsomely for them. No impoverished peasant or worker in, say, Benin or Belgium could do such a thing: these folks did not fly very frequently, if at all; hence they produced no unavoidable emissions; hence negative emissions technologies need not be hitched to their lifestyle. If it were up to the market to allocate unavoidability and the removal conjugated to it, such technologies would by definition flow towards actors with money – a.k.a. the heaviest polluters. What removal society could afford would be set apart to compensate for the emissions from the Bill Gateses of this world, while 'displacing needs from sectors with high public value but limited private ability to pay (for example, farming, remote hospitals)' – or, what rice farmer in Bangladesh can buy credits from Climeworks?[243] Insofar as it is left to the invisible hand to arrange these matters, this scenario seems truly unavoidable. A billionaire has greater purchasing power than a Bangladeshi labourer and will be able to claim more removal capacity – so much capacity not used for subsistence or survival, including return from overshoot. The more removals used for offsetting, the less available for reversal.[244] Late value form becomes the underwriting of luxury.

Bullshit credits

The appendix of caveats tells us that removal has to be organised within strictures and with circumspection. But the carbon market does not defer to such principles. This market does not sit comfortably in a straitjacket – no market ever does. By the early 2020s, the invisible hand had the field of removal firmly in its grip. The growth imperative pulsed through it like an electrical current. A newly minted startup would not be interested in restricting the sale of credits – that would amount to self-harm, guaranteeing its going out of business. Pioneers could not afford 'stressing too much' about who was purchasing their credits, one prominent advocate argued – frustration in his voice – when confronted with the case for circumspection. 'We gotta take the wins where we can get them.'[245] The realities of the market forced each company to stay 'focused on acquiring market share, developing secure intellectual property, and minimising unit costs', the carbon market here being no different from any other.[246] It was characterised by rashness not self-restraint. The investors who piled into it wanted their money to grow, as it would if seeded in any other field.[247] But wasn't this compulsion just what removal needed most – a mechanism for scaling up at maximum velocity? Who could bring negative emissions technologies from infancy to maturation in a flash, if not a market predisposed to a high rate of compound growth? We shall return to this argument shortly. Here we shall first inspect a problem of quality.

The premise of offsetting was, of course, that the certified activity would actually draw down CO_2. If that never happened, or if it happened to an extent far less than promised, the equation would fall apart. The road to net zero was paved with failures in this regard. Carbon credits would multiply in gluttonous quantities, but they would often be of such poor quality that they did not compensate for anything. This problem beset the market from the days of Kyoto until the latest phase of the Paris era: there was 'a persistent pattern of exaggerated climate benefits' from the credits sloshing around.[248] Investigation after investigation found that operators of projects massively inflated them, about as loyal to the truth as the average advertisement campaign.[249] In the year after Paris, the European Commission was served with a balance sheet for the Clean Development Mechanism: 85 per cent of projects had been overestimated and may not in fact have kept any CO_2 down on Earth.[250] On the California market, 80 per cent of offsets 'likely do not represent true emissions reductions'.[251] On the

Australian market, 80 per cent ‘experienced negative or negligible change’ in how much forests had actually grown over their duration – these offsets still being heavily dominated by the (supposed) planting of trees.[252] Chaos reigned in the unregulated, voluntary market where removal startups were pitching their tents in the 2020s. A survey by the *Guardian* based on three separate studies concluded that over 90 per cent of all forest credits approved by the world’s largest certifier ‘did not represent genuine carbon reductions’ and so were ‘largely worthless and could make global heating worse’.[253] They were ‘phantom credits’, with next to no impact. To buy them really was to buy indulgences, making the heating worse rather than ameliorating it. And all the money tipped into this void could instead have been used to fund climate action.

The quality problem was directly inherited from Kyoto and extended into the 2020s, first and foremost to credits based on trees. These still ruled supreme worldwide. Durable removal might have been the future of the market – such was the hope – but it was still a niche, the perishable volumes three to four times larger.[254] As late as 2020, ‘more than 99 percent of the carbon removal volume we selected was from natural solutions with durability terms of 100 years or less, such as forest and soil projects,’ Microsoft reported.[255] Not only did removal of this kind weigh as lightly against emissions from fossil fuels as a feather against an oil platform, credits based on it were also, as we have seen, prone to take on a pure phantom character. ‘We’ve bought forest offsets that are now burning,’ said a Microsoft manager during the wildfire season of 2021, evidently distressed.[256] If you have bought offsets meant to remove emissions on the negative side of the ledger and these go up in smoke, you have achieved exactly nothing: the sins are wholly unatoned for.[257] Late believers clung to the redeemability of the market – if only one could give priority to ‘high-integrity’ offsets, or ensure transparency, or fly enough satellites and drones over forests, the substance of removal could be saved – but this merely moved the problem into other fields, in familiar fashion.[258] It was also another echo from the Kyoto era. ‘I am having the same conversations about quality that I was 20 years ago,’ one frustrated academic told a journalist.[259]

Time and time again, ‘offset programs become large, cheap and low quality’, Danny Cullenward and David Victor have observed in *Making*

Climate Policy Work.[260] The market was built around minimal regulation and oversight. Most actors involved had an interest in keeping it that way. All worked to inflate a bubble of fictitious credits that had little if any relation to reality. Big buyers needed a lot of offsets to back up their claims about being or becoming neutral or negative and so sought to pump up as many credits as possible: quantity took precedence over quality. Offsets were the show ponies they paraded around in advertisements and on product packages to demonstrate just how much they cared.[261] On the other side of the counter, project developers and certifiers had an incentive to sell as many credits as possible: a primacy of quantity again, creating 'a race to the bottom that is hard to emerge from'. All parties gained from 'excess crediting'.[262] To forcibly raise the quality of the offsets would curtail the quantity, depriving buyers of their medals and sellers of their merchandise.[263] Talk of overcoming this imbroglio by means of advanced monitoring devices was little more than putting lipstick on a pig.

The quality problem was intrinsic to the structure of the carbon market, and it very much applied to durables too. As we have seen in the appendix, every negative emissions technology had side effects and potentials for inversion into nullity or positivity. But for (almost) every half-baked idea that popped up somewhere in an academic journal, there soon was a startup that sought to make money out of it. It mattered little how much CO_2 was actually being removed; the money was made out of the *perception* that this was happening, or was about to soon happen, or could happen if all went well. A suspension of critique was part of the game. No offsetting contracts had space for appendices or footnotes sowing mistrust. The result was a collective state of delirium: 'The science is getting lost amid the carbon removal gold rush,' one journalist dryly concluded.[264] The more companies joined the stampede, the more cocksure they had to sound about their own chosen tech, the louder the noise and the further away from strictures and circumspection the whole space seemed to drift. Seaweed was perhaps the cutting edge of this scramble in the early 2020s. As we have seen, the startups choosing that tech made the explicit choice of running ahead of the science – including the science of whether seaweed would capture any CO_2 at all. But the problem extended from wildebeest and whales and oyster banquets all the way to the conduct of carbon inside Icelandic basalt. Phantom objectivity kept being produced in novel shape. Late value form,

in other words, not only lets the production of exchange-value override the use-value of removal. Inherent to it is the *shoddiness of the use-value itself*.

Some buyers were prudent and picky enough to deselect the poorest quality credits. Microsoft appeared to be one, but even this luminary did not do so consistently. It bought a few thousand credits from Running Tide, despite the rubbish reputation that company held. Now, if even relatively refined customers fell into this trap, what about more easily placated consumers? Economics decreed that they fill up their shopping carts 'as cheaply as possible'.[265] 'Offsets consistently end up with low quality in the real world because the forces that prefer quantity dominate those that prefer quality.'[266] These were not conclusions derived from theory. The investors prowling this space identified it as the law that ruled the market, or, as one of them told us: 'every buyer' is 'trying to get the most for the least'. The bulk are focused on minimising cost; for many 'even $5 a ton is a lot', and so what they end up buying is 'very low-quality credits'.[267] In the end, most end up eating at McDonald's.

That deluxe credits would win out on their own merits is about as likely as organic and fair-trade food taking over and finishing off the junk spontaneously, in the absence of regulatory intervention. If there is ever going to be mass demand for removal, it will be for the cheaper varieties. An augur of this future was given in early 2024, when the Science-Based Targets Initiative – a kind of synod sanctifying the best and most durable types of removal, which conscientious customers would then be pressed to choose – suddenly extended its blessings to all kinds of offsets.[268] Purchasing companies rejoiced, welcoming the new 'flexibility'.[269] Indeed, many had long whined that living up to the Initiative's high ideals was 'too much of a challenge'.[270] Some laxity would be for the best. 'Carbon credit programs would benefit from a bigger pool of interested buyers, and companies would be able to meet their emissions reduction targets more easily.'[271] Among those lobbying for a liberalisation was Jeff Bezos's private Earth Fund, 'a major supporter of a push to scale up voluntary carbon markets'.[272] The Biden government, in the guise of the former climate czar John Kerry, had persistently weighed in too.[273] To gorge on credits, the representatives of the status quo seemed only to wait for the opportunity to ditch any science-based asceticism.

Size is not all that matters. If a credit bubble reaches jumbo scale but is filled with hot air, little will have been won for climate. The only certainty is that buyers will then have used those offsets as an alibi for continuing to shoot CO_2 molecules into the sky, worsening overshoot and adding to the total amount of removal needed to reverse it. But then this is, of course, exactly what has been happening all along.

Sleep on carbon dioxide, dress in it, get drunk on it

Let us take stock of what we have seen so far. Late value form develops through a series of interlaced circles. Primitive fossil capital invests directly in negative emissions technologies to preserve itself, through everything from impression management to enhanced oil recovery. Fossil capital in general purports to offset its emissions. The grandees of fossil consumption appropriate removal capacity to make up for what they release through luxury. Suppliers of credits unite with buyers in inflating quantity, as a way to keep producing exchange-value on each side, to the detriment of the quality of the use-value. Money flows without cumbrance between all these circles. But now another loop also reveals itself to the entrepreneurial mind.

When DAC plants pullulated from gulf to gulf in the early 2020s, very few actually locked away the CO_2 they had caught. Most had part or all of their precious haul converted into commodities. Hinwil sold it as fertiliser and fizz; others as shots for enhanced oil recovery. It could be marketed as a refrigerant in supermarkets or a respiratory stimulant in hospitals or a solvent for extracting flavours. This was something else than removal: it was carbon capture *and utilisation* – or commodification. The opportunities stretched far and wide. Many jars on the shelves of markets could be filled with captured CO_2. Fuels are one. Pure CO_2 can be made to react with hydrogen and other commonly occurring substances and refined into copies of diesel and gasoline – synthetic fuels, derived from carbon floating in the air. This alchemy has a century-long tradition. It originated in the Third Reich and apartheid South Africa. Both entities were cut off from the oil supplies they craved; both exerted their utmost effort to produce synfuels as surrogates. In 1934, the former opened the first plant using the Fischer–Tropsch process for converting carbon atoms in gas form into liquids; at the

height of the sanctions, the apartheid regime made further strides.[274] DAC could stand on the shoulders of these giants. ‘As shown by Germany during World War II and by South Africa during apartheid, manufacturing artificial gasoline is readily doable,’ Broecker waxed hopeful.[275] In the late 2010s, DAC companies and their partners in oil, gas, auto and aviation began experimenting with the Fischer–Tropsch process to optimise the transmogrification of air into fuel, dispatching a steady stream of progress reports. Climeworks struck a deal with a Norwegian consortium to build the first plant for producing fossil-free jet fuel. It brought Lufthansa into the collaboration. A combination of the Swiss filters, Norwegian water and wind, the latest German engineering skills and the old Fischer–Tropsch formula would, from 2026, if things went according to plan, allow planes to fly on ether.[276]

Synfuels could open one of the largest markets in capitalism to DAC.[277] Planes, cars, trucks, ships could – such is the vision – all switch to synfuels, chemically identical to what came before them. In the writings of Climeworks, this was the supreme deliverance from ‘abstinence’: wherever we wanted to go with fossil fuels, we will soon be able to go with air.[278] Musk thought it would one day power his rockets to Mars.[279] Carbon Engineering worked on ‘a process that we call Air to Fuels™’, the products from which would be ‘compatible with existing refineries and engines’.[280] Shell had similarly high hopes.[281] And onto this stage stormed Rob McGinnis, a former playwright, dressed in the Silicon Valley uniform of jeans and black T-shirt: he promised to sell gasoline made solely of air, water and renewable electricity in American gas stations by 2021. He said it would be as cheap as the fossil original. It would crowd out the lot. McGinnis had some experience with mammoth projects and removal exercises; during the first Iraq war, he cleaned mines from battlefields and harbours in the Gulf.[282] The startup he owned, aptly named Prometheus, received a financial injection from BMW in the summer of 2020.[283] Come 2021 and not a gallon of aerial gasoline had been generated. McGinnis blamed the pandemic. ‘I feel like I got myself in trouble because I predicted things and then covid happened,’ he pitied himself, and renewed the pledge – hedged with a ‘maybe’ this time – to begin shipping in 2023.[284] Come 2025 there was still nowhere to purchase the promised fuel. But the hyper-futuristic website kept trading in promises. Prometheus, it now claimed, had

revolutionised Fischer–Tropsch and invented a version of DAC that could catch carbon for no more than 40 dollars per ton. ‘So we celebrated, in classic Prometheus style. We filled a bike with our fuel and gave it to a stunt driver who put on a show, gifting us some wheelies and knee drags and a daring feat.’[285] It was hard to know how serious to take all this posturing; a healthy dose of scepticism seemed in order. Meanwhile, other free minds took things a step further still: they spun on the idea of mobile DAC and imagined cars thus equipped producing their own fuel *while driving*, the late modern version of a perpetuum mobile.[286]

They called themselves ‘air miners’.[287] Forming a distinctive ‘space’ – the generic business term for a community of startups, researchers and investors, reeking of air-conditioned conference rooms and slick presentations – they threw out one commodity after another. One New York–based outfit tied CO_2 into polymers and manufactured sneakers, spotlessly white, designed for the finest boutiques: the first ‘shoe without a footprint’ (courtesy of some financial assistance from NRG Energy, which ran nearly 100 fossil-fuelled power plants in the US).[288] A German enterprise fabricated foam for mattresses (‘Sleep on carbon dioxide? Absolutely!’). Air Protein™ cooked ‘the world’s first air-based meat’. Air Co. went for vodka, Novo Nutrients for fish feed. Lanzatech made yoga pants. Twelve made sunglasses and components for Mercedez Benz cars. Two companies claimed to be compressing air into diamonds. One, Go Negative, offered customers a sooty, black bracelet of mineralised CO_2. AIR Eau de Parfum sold out its first bottles of ‘fragrance made from CO_2’ – a ‘genderless scent inspired by Earth’s most vital elements, reminding us that we are not separate from nature’.[289] With that, it would be possible to dress in diamonds and smell of perfume and drink vodka *all* manufactured out of CO_2 snared from the air.[290]

Once the strong bond between the carbon and oxygen atoms in CO_2 has been broken, the owner has in his supply the most versatile element, out of which all manner of compounds can be elongated and combined; and so there occurred a secondary Cambrian explosion, spawning not negative emissions technologies but commodities produced from CO_2. Because nearly everything is made of carbon, air can now, in chemical principle, be transformed into nearly anything. Quorn and other kinds of protein may

feed humanity from the air.[291] Feedstocks for plastics and other hitherto petrochemical products may be taken from the same source.[292] So may decking boards and bricks.[293] Of particular promise, carbon could be baked into concrete and asphalt, sometimes referred to as *ex situ* mineralisation – the CO_2 locked up not in caves but in the fabric of cities.[294] DAC could conquer the construction industry too. Made of Air, Carbon Cure, Carbon Limit, Carbon Infinity were the names of some of the ventures gearing up for this thrust.[295]

By 2023, there were nearly 700 of these companies out there.[296] Going beyond DAC, they offered so many ways of transforming CO_2 into some physical product. They outnumbered the offset producers by five to one. For every dollar of investment that the latter conjured out of thin air, the commodity producers summoned eight.[297] Seven in ten of the XPrize finalists were 'focused on producing products'.[298] Durable offsets might be booming somewhere in their own little corner, but clearly capital in general was occupied elsewhere.

What else can you sell?

There was a problem here: the circle of utilisation had a troubled relation to removal. Of all the things CO_2 could make, very few had the potential to sequester carbon for more than a century, the absolute minimum of permanence. Concrete and asphalt were two of them, biochar perhaps another.[299] Every other product was but an inhalation into the commodity form, keeping molecules in place ever so briefly before they slipped back out.[300] The gas would be back in the atmosphere by and by, quite possibly in larger quantities (if some fossil fuels are burned in the process of capture or if the capture speeds up the extraction of fossil fuels).[301] Whatever synfuels anyone managed to manufacture would exhale CO_2 in the moment of combustion; vodka and fragrance would let it out through mouths and armpits. Bracelets might hold the element for some years, but there will be wear and tear and losses: such finery is not meant to be hidden away in chests. 'Certainly it represents a beguiling opportunity – convert a waste

product into high-value end products,' one research team observed, in the tone of muted exasperation characteristic of the finest climate science; but the vast preponderance of the utilised CO_2 'is immediately released to the atmosphere', and so this whole business is 'highly unlikely to ever be a realistic alternative to long-term, secure, geological sequestration'.[302] So why would anyone pick this option?

The reason is as obvious as it is mundane and exasperating: 'CO_2 utilisation strategies, while in their nascent stages, offer the alluring possibility of turning CO_2 into *valuable products*,' explained one article excited by this 'holy grail'.[303] Sequestered CO_2 bears no exchange-value. Laying it to eternal rest means, by definition, forfeiting it – never seeing it again, never touching it, much like a corpse in a tomb. The Wood Vault or Vaulted Deep would be just that: deceased matter dug down a grave. Mineralised CO_2 becomes one with the rock or fodder for bacteria. Inside this sepulchre, the carbon is not a commodity on the market: it exists as a negation of the commodity form – or, in the dispassionate terms of two scientists of chemistry and energy: 'By its very nature, this has no commercial value.'[304] Offsets promised to fill this void, but that market, as we have seen, was designed for trading cheap junk credits; the sellers of durable removal faced a steep challenge in making money there.[305] And offsets could only ever generate value, of course, by giving free vent to *other* emissions somewhere else, thereby again negating the supposed negation. If you bury CO_2 and promise to never use it again, and your way of making money from this act is to sell the credit to someone who wants to offset an equal emission of CO_2, no net sequestration takes place. But under capitalist property relations, somehow the private sequesters have to find a source of profit. Wherever they turn, the result is to contradict the purpose of their operation.

Put yourself in the shoes of the owner of a DAC plant: you have a tonne of pure CO_2 on your hands. What are you going to do with it? You can package it as a commodity and sell it to a customer willing to pay or go to some far corner of the earth and bury it, hitching your fate to the uncertain fortunes of the offset market. You are running a company. You have invested your own and others' capital. What course of action do you take? For many, the answer was blatantly obvious. (And the same answer might

help explain why the market in durables tilted so heavily towards the production of biochar: it was that seldom thing, a technology that promised to remove CO_2 while simultaneously having clumps of it packaged up as a supplement to feed hungry soils, the latter being 'a tangible thing that can sustain a business'.[306]) In an uncertain policy climate and with the offset market on unsure footing, having a physical product to sell was 'incredibly advantageous'.[307] No wonder the more well-trodden paths of commodity production beckoned. But in that very moment, of course, the contradiction only deepened. Where offsets create value by cancelling out removal against continued emissions, commodification for the most part did so by foregoing removal altogether. The two were just different iterations of the same compulsive draw of late value form – of the same fundamental contradiction between sequestration and value.

This contradiction structures the space. When we spoke to Nicholas Eisenberger, the son of Peter, who rose in the ranks of Global Thermostat after its internal crisis, we asked him about the relationship between utilisation and sequestration. Only the latter might take CO_2 out of the atmosphere and have a thermostatic effect, yet companies in the field were preoccupied almost exclusively with the former. He likened sequestration to a vaccine. The following exchange ensued:

> WC & AM: Just to stay with the analogy here. If you have a vaccine, you have a product for which there would be huge demand, obviously.
> NE: Yeah, exactly! Fucking climate change, stop the planet from melting. Huge fucking demand.
> WC & AM: But in this field, what's the product that you can turn into a market opportunity?
> NE: I don't mean to be cheeky here. Life. On Earth.
> WC & AM: Sure, but is that something you can sell?
> NE: Let's just stick with that. What else can it be. What else can you sell? That's a great quote, I love it. So unbelievably absurd, that's the leap we haven't made, right there, you just said it – life on Earth, is that something we can sell? That's our problem, that's where we're stuck.[308]

Why, then, had Eisenberger's company simply vented the CO_2 it captured at its first facility in Colorado back into the air? Because it was a trade show: Global Thermostat sought to demonstrate that its technology worked and impress customers who needed the commodity and would later come and pick it up. Unable to sell life on Earth itself, Thermostat found it rational to just squander the CO_2 while it waited.[309] This company seemed to have had

a tortured soul. The two founders were aware that a lowered atmospheric concentration of CO_2 would be a public good without boundaries.[310] If a DAC industry in the US were to reduce it to 350 ppm, the same good would extend to Mozambique and Mexico and every other country on Earth; there is no available option for enclosing it on a national, let alone private, estate. And, in the next breath, Chichilnisky would say that she was busy 'making the carbon dioxide removed from the atmosphere the new petroleum'.[311] She had, after all, formed a company subject to the market imperative.

Once a DAC company started eyeing the utilisation market, another problem soon emerged. In Iceland, there was one startup besides Climeworks selling the vision of capture from the air. It was called Carbon Iceland and originally aimed to team up with Carbon Engineering in a remote spot in the north of the country. Inspired by the idea that CO_2 would be 'the gold of the future', it planned to build synfuel plants. But when it started approaching the likes of Siemens and Mitsubishi to help fund this dream, it was met by deep frowns. 'Investors always ask questions that the noble mind does not ask,' a representative of Carbon Iceland told us. DAC, the startup would hear, was cute and nice, but there were 'other ways of getting the CO_2 at a fraction of the cost'. Industrial facilities produced enormous amounts of the gas; they would be a much more efficient source of it than a dilute atmosphere – so why didn't the startup go for that instead? Faced with no other choice than to follow the money, this was indeed the path that Carbon Iceland then took.[312] This was classical CCS, of course: here the gas would not originate from the air but from fossil fuels, then put through a recycling loop before finally being released. It was fossil fuel combustion with a slight delay in emissions, a circle still more distant from removal. But the logics of utilisation did not necessarily bother about that distinction. Caught up in the net of late value form, through one route or another, the captured CO_2 would always be brought back to the atmospheric surface.

But then there's no business

In May 2024, the crème de la crème of the removal industry gathered two blocks away from Wall Street for a conference called ‘Carbon Unbound’ (slip of the tongue, as the point of the exercise would presumably be to bind the carbon). Rain banged on the large windows. The CEO of Skytree, Rob van Straten, gathered half a dozen attendees around him for a ‘campfire session’, meaning an intimate, honest conversation over a table. He began by lamenting the fact that when CO_2 ‘is utilised, the problem is amplified. Emissions are not gone, and because energy is used in capture and transport, there is more of them. With sequestration, the emissions are gone – but then there’s no business in the CO_2!’, he exclaimed with an awkward laugh, as if resigning to the absurdity were tragicomic.[313] Skytree’s schtick was to sell DAC devices. It could make as little money on sequestration as anyone else, but it could market its proprietary technology for capturing CO_2, the greenhouses of the Netherlands the main source of demand so far. It was also looking into beer and plastics and synfuels. ‘We want to build DAC plants on top of industries that use CO_2, no transport needed – it’s going to be a big market,’ van Straten confided. ‘A molecule that was always known to be harmful now has the potential to be turned into valuable applications,’ he accepted.[314]

At one point during Carbon Unbound, the storm raging in the financial district became so obviously violent – thunder and lightning going off, rain throwing itself against the window screens as against the walls of a castle – that the assembled entrepreneurs had to comment on it: ‘This is distracting, while there is a storm out there,’ said the CEO of Carbon Limit, his tone apologetic.[315] The conference veered between moods. On the one hand, it gathered the world’s greatest enthusiasts for removal in one venue. On the other, a recurring theme was the paucity of demand. Apart from Microsoft and the enhanced oil recovery no one spoke about with pride, there were not enough buyers around, either of credits or concrete commodities.[316] When someone in the audience asked how removal can become like a vaccine, rolled out at maximum speed, Tito Jankowski, the CEO of the portal AirMiners, turned blue on stage: ‘We don’t have a plan. And we need a plan. We need to triple the amount of CO_2 removed this year, next year, every year to 2030 and beyond. Who removes this amount of carbon? Who pays for it? Optimism without a plan is just wishful thinking.’ The space seemed afflicted by doubt about whether ongoing trends were enough to get

the ball of actual removal rolling. A poll was organised, the 200 or so participants asked if they thought one gigatonne could be accomplished by 2030: only 14 per cent answered ‘yes, we can’. The rest were divided roughly equally between ‘hmmm, it will be tight’, ‘I wish, but doubt it’ and ‘definitely not’.[317] The pioneers were evidently weak in their faith, unconvinced that utilisation and commodification would bring them closer to the goal, yet unable to pursue any other path – ‘for I have the desire to do what is good, but I cannot carry it out.’[318]

This logic became brutally concrete just a few weeks later. When we interviewed Running Tide in April 2024, the company’s Icelandic lead observed, half-laughing because the fact was so patently obvious, that they were deeply dependent on offset funding. If this market ‘just doesn’t become a thing, then we’re not a thing’. If nobody forces companies to offset, then ‘nobody will pay in the end’, except for ‘very few, very proactive companies’. Just two months later, Odlin announced that Running Tide was ceasing all operations. ‘We are unable to secure the right kind of financing to continue our work,’ because ‘there simply isn’t the demand needed to support large scale carbon removal.’[319] During its short lifetime, the company had raked in millions and signed offset contracts for thousands of tonnes, and yet it still fell short. It was the first high-profile casualty in this space. But a second followed half a year later in the form of Nori, a pioneer not of seaweed but of removal in agricultural soils, of better repute and standing. It ran a ‘marketplace’ for offsets from farmers who adopted carbon-boosting practices: and it too shut shop because of ‘challenges of a stagnant voluntary carbon market and tough funding environment’.[320] Soon after, there was also a casualty in the BECCS niche. Less flashy, less start-uppy but no less weighty, Swedish state-owned energy company Vattenfall buried plans for building a capture device at one of its biomass power plants just south of Stockholm. ‘The market for carbon capture is immature and the economic conditions to realise the project are missing,’ Vattenfall drily announced.[321] There really were only so many Microsofts and Googles to go around.

For Odlin and Nori as for the people congregated at Carbon Unbound, the problem was not one of intention. Anyone in this space could be as desirous of a liveable climate as any rioter risking limbs on a barricade. A will to do good deeds was not the missing element. People who went into startups to develop the best item in the catalogue sincerely wanted – so we

must assume – to contribute, to the best of their professional abilities, to saving the world.[322] In *Planetary Improvement: Cleantech Entrepreneurship and the Contradictions of Green Capitalism*, a careful ethnography of the broader 'space' of clean tech preceding removal – renewables, algae, smart grids, nano-materials – Jesse Goldstein describes how things tend to go awry when well-meaning people try to put goods on the market and have to secure funding, attract investors, appeal to buyers, outdo competitors, sell commodities.[323] A law gets to work on them other than the law of their minds.[324] The former regulates every circle of late value form – but then there are also, of course, actors whose inner submission to it is so deep as to manifest as darker desires: 'Putting CO_2 in a saline reservoir is a waste of a valuable product. It's something we should not do on a large scale. It's missing an opportunity to produce net-zero oil,' said Hollub of Oxy.[325] 'I think longer term, you move from storing CO_2 to converting it to a product the world needs,' said Woods of Exxon.[326] Under that law, there will never be reversal.

Travails of the carbon commodity

But is there no way sequestered CO_2 can generate a stream of private revenue? In the early 2020s, Climeworks relied on one thin method: offering individuals with spare cash certificates of removed CO_2, to be bought just for the sake of it. In the web shop, customers could subscribe to get 740 kilograms of stone sunk into the ground over a year; the more magnanimous could specify a higher amount. They could purchase gift cards to get 'their loved ones started on their journey to climate positivity': printable from any device, a diploma for seven kilograms permanently removed per month.[327] This was virtue shopping. There was no commodity involved other than the knowledge that one had financed the burial of a sliver of CO_2. Or, as one consultant and expert in the Canadian wing of the space put it to us:

> Carbon removal is an odd thing to try and value in the market, right? You as a private citizen can go and pay for removal credits, but you don't get anything. There's no physical product at

> the end of the day. We're valuing basically this digitised certificate: you pay for a tonne of CO_2 to be removed from the atmosphere, and that's great, congratulations. But you don't get something; you don't have something you can use at home. It's not a physical good. It's an interesting way to think about a commodity where there's no sort of exchange-value. You are paying some project developer somewhere to pull a tonne of CO_2 out of the atmosphere and store it safely, durably over the long term.[328]

How far could it bankroll sequestration? Would the rich of the world pick up the check for 'life on Earth', much as they acquired a taste for Tesla (a model for Climeworks) – and this on the scale of tens of gigatonnes per year? But then why would anyone buy these certificates, if not to offset some less salubrious activity? This, indeed, was what Bill Gates was using them for, as, presumably, did many of the company's other customers.[329] In which case, we are, of course, back in the morass of the carbon market. The idea that the rich would give up their fortunes to fund mineralisation sufficient to turn the tables on the atmospheric concentration *without getting anything else in return* beggars belief – a belief that not even Climeworks seemed to possess. Self-effacement and monetary fortune rarely go together.

Not only DAC, of course, was strapped in this logic. Any technology that produced a pure stream of CO_2 – from BECCS to DOC – would be in the same situation.[330] One could capture CO_2 in microalgae and turn them into food or fuel.[331] Photosynthetically enhanced trees would be seductively high-performing inputs in any process of production using wood.[332] Living Carbon admitted that 'yeah, this will be a tree plantation', the company's goods ready for harvest earlier than the unmodified species.[333] In short, 'atmospheric CO_2 through biotechnological processes can be converted to products of value.'[334] It would be wasteful, on the criteria used by people like Hollub, to just let forests regenerate themselves – where would the profit be in that? – and so not only credits but commodities had to be grown out of them: much of the forestation underway was slated to produce timber.[335] Commodification everywhere threatened to negate the concept of negative emissions technologies; but perhaps DAC had a special vulnerability. Late value form stood in the way not only of real removal but also of decentralisation and the use of excess electricity from solar and wind. As we have seen, a programme of stop-and-reverse might best be founded on the moments when such sources generate a glut, with the DAC devices standing still on other days. But private DAC companies would

have loans to repay, funders to keep happy, contracts to honour, profits to make. Any day when the fans are not spinning would be a day lost.[336] Capital has always abhorred interruptions; it will do so here, too, and chafe at the notion of a DAC system designed for intermittency.

Against this sort of critique, a retort was common: the market might not take us to the final destination, but it is the propulsive force that starts us on the journey. If you want to lose weight, taking amphetamine will not be the lasting solution. It just sets you on the right track. If the telos is actual permanent removal that brings the CO_2 concentration down, you will get there via 'the very valuable strategic pathway' of utilisation – one more detour for the overshoot conjuncture, one more bridge: DAC companies will sell CO_2 across the commodity spectrum, in every niche, large and small; the technology will get a chance to develop and prove itself; costs will plummet, skills accumulate, the number of plants increase by leaps and bounds, until they are potent enough to take on the atmosphere for real.[337] In Nicholas Eisenberger's blunt terms: 'I almost don't care how you do this, whether it's durable carbon or not – you've just got to get more practice in. You've got to shoot more goals, and just get better and better.'[338] Somewhere down the line, DAC will have amassed the force to flip on planetary-scale sequestration. Beggars cannot be choosers. What matters is the takeoff: a swerve towards removal can happen when the tech has approached cruising altitude.

Did anyone really believe in this? Possibly, but the counter-objections leapt to the eye. What is to say that an economy adjusted to utilising CO_2 will – at that very point – let go of it? If recycled or 'upcycled' CO_2 really were to diffuse throughout the lines of commodity production, there would presumably be an interest in continuing to drink from this well (or taking this speed). If the world's aviation industry begins to fly on synfuels from Climeworks, it would hardly be delighted about having that resource suddenly reallocated to the underworld. It is rather as if the manufacturers of steam engines conspired to start blowing them up in the moment of their widespread adoption. The risk, in other words, is that DAC will never make it to the other side and, moreover, that the longer it travels on the bridge, the farther away it will move from that destination.[339] A lot of assets created along the way would have to be stranded for a transition to removal.[340] If the market for offsets provides the initial stimulus, the outcome would be

the same: any built-up capacity for carbon capture would be affixed to a planet of value.[341]

But the greatest threat arguably comes from enhanced oil recovery. To make CO_2 a commodity is to give it up to this practice: in the mid-2010s, enhanced oil recovery represented 97 per cent of the global market for the gas.[342] Every other form of utilisation was, as of the early 2020s, puny next to it.[343] People who believed in the passage through the market thus had to make the case for enhanced oil recovery as a gateway drug to removal. They said that it would work as 'a kick-starter' for or would 'jumpstart' DAC.[344] Carbon Engineering sometimes argued that the whole point of recovery was to boost the tech so much as to ultimately make 'it economical to just bury the carbon dioxide in the ground'.[345] Oil and gas companies would lend their know-how.[346] The argument was even made that because hydrocarbons are so fabulously high-priced and profitable, the only way for DAC to yield a profit is to piggyback on it.[347] But if enhanced oil recovery were to enter a boom similar to fracking – precisely what these voices were rooting for – the result would, of course, be *another epochal round of accumulation* in the circuit. Primitive fossil capital would have even greater profits to swim in, with which to expand operations even further. It would sink even more fixed capital into the beds of inertia; indeed, the very construction of costly facilities like Stratos added to the assets that must not be stranded. A DAC/recovery apparatus would not be voluntarily relinquished for removal – it would be the negation of the promised negation, raising yet another technological layer on top of fossil fuels, this time stolen from what was supposed to be the arsenal of restoration. If drawdown is ever going to happen, it needs to be the exclusive focus from the start.[348]

This is not to suggest that carbon commodities were about to take over the world. The late neoliberals of utilisation were in a pickle. For conspicuous reasons of thermodynamics, any commodity derived from the atmosphere is at a competitive disadvantage vis-à-vis the fossil-fuelled incumbents. It is much cheaper to make plastics from petroleum than from air. The fantasies of a McGinnis were delusional. Only some heavy financial penalty on emitting CO_2 – a price, a tax, a rationing system – could ever enable synfuels and other products of DAC to seize market shares.[349] 'Policy needs to come in, and quickly,' ran a phrase common in

the space.[350] ‘Carbon Engineering, for instance, says it’s banking on government subsidies to make the economics work.’[351] The same strange scene played out in the removal offset market, the chorus of believers culminating in a collective pining for regulation. ‘Everybody’s talking about the lack of demand,’ one expert divulged, private customers unable to generate sufficient demand of their own volition.[352] The state would have to force them to buy credits for demand to grow. ‘We’re not going to achieve this with voluntary contributions’; ‘it’s got to be compliance,’ otherwise ‘we’re done. We’re all screwed.’[353] ‘There’ll need to be a compliance market.’[354] ‘We need policy-induced demand at gigatonne scales,’ and so on.[355]

Banking on a broader commodification of carbon, then, presupposed a massive programme of state intervention as a necessary condition of possibility.[356] Much as the space swung in bipolar fashion between mania and depression, it had a schizoid relation to the state: it resisted the scenario of collectively funded sequestration for the public good – which, tautologically, would end the reign of late value form – while hoping for the state to step in and catalyse the market for their products. As of the early 2020s, no significant steps had been taken in this direction, save for Biden boosting enhanced oil recovery (and, on the offset side, the EU contemplating the inclusion of removals in its existing carbon market).[357] But this did not prevent elements of the bourgeoisie from imagining that it was about to put the capitalist mode of production on an entirely new material footing.

Eat your faeces

Visionaries who did not care much for thermodynamic constraints saw before them a novel economy on the rise. The all-purpose raw material can soon be downloaded from above.[358] With carbon in the air, plenitude is at everyone’s fingertips. Global Thermostat imagined a progression from fizz to steel and ‘tons of other things’ and predicted that word would eventually reach ‘somebody in the Kalahari Desert. A bush tribesman’ could create his own air-based emporium.[359] Futurist tech guru Peter Diamandis foresaw the

logical next step: ‘Beyond Earth-bound utility, DAC could hold countless vital applications in extra-planetary ventures. With a 98 percent CO_2 atmosphere, Mars could be an ideal target for DAC, not to mention an optimal source of needed commodities.’[360] But here on Earth, the vision was for the CO_2 generated by two centuries of fossil capital to descend to the living *in the shape of a resource*.

This vision had a home in the towers of Saudi Arabia. In 2006, Aramco organised the first international symposium on ‘carbon management’ – 400 participants, 100 institutes and companies from two dozen countries in attendance – searching for ways to bring back the CO_2.[361] A hiatus ensued, but in 2020, when Riyadh hosted a G20 summit, the kingdom announced the new credo of a ‘circular carbon economy’. It was defined as a ‘voluntary, holistic, integrated, inclusive, pragmatic and complementary approach to promote economic growth while enhancing environmental stewardship through managing emissions’.[362] A little catchier, the circular carbon economy was summed up in the four injunctions ‘reduce, recycle, reuse, remove’.[363] This was what the ideologists of the kingdom wanted to do with the carbon, together with the rest of the G20 and humanity. Then a bright new future would open up.

But as usual, that future looked suspiciously similar to the past and seemed to be attractive in proportion to the similarity: ‘Fossil fuels will continue to play a major role in the future energy mix,’ a disquisition laid out; this means that ‘CO_2 emissions will also remain a reality for the future’. Turning these emissions into commodities, however, ‘restores the carbon balance’.[364] Or, in the succinct words of the Saudi energy minister: ‘Carbon is not the enemy.’[365] All the writings that poured out on the subject were based on the premise that fossil fuels are the future.[366] This was not exactly original; but what was original about the circular carbon economy was the notion of *converting the waste into value*. In the words of the minister: ‘Carbon is a resource. It is not something that we should just throw and just emit it. Actually, capturing it *lets us make money out of it*.’[367] The vision was for primitive fossil capital to make profit on fossil fuels *and then make profit again on their emissions*. How did Aramco plan to go about this? It brandished projects for enhanced oil recovery as well as the production of methanol and ammonia from captured CO_2 and, of

course, its various assays at DAC.[368] But the circular carbon economy might have had its greatest power as sheer creed.

It caught on in the West too: a Circular Carbon Network set up by Diamandis's – and later Musk's – XPrize spoke about a first industrial revolution sparked by the steam engine and a second upcoming season powered by the pollution made since then.[369] Unilever and other colossi of the petrochemical industry bought into the message.[370] So did the US Department of Energy (under Biden) and Climeworks.[371] Researchers pitched in with schemes for indoor DAC as particularly useful for grounding this circularity, as it would have an easier time with thermodynamics; some envisioned air conditioning systems doubling as DAC devices and producing synfuels inside apartments.[372] Everyone would have the equivalent of an oil well at home. This would be 'crowd oil'.[373] Note that this philosophy differed slightly from Lackner's. When he drew up his image of a sewage system, he based it on the CO_2 actually being sequestered, the DAC toilets flushing it out of the active carbon cycle. Here the molecules would rather continue circulating forever, because all manner of enterprises would eat them as input. If there is biological metaphor applicable here, it would be autocoprophagy. How can we make sense of it?

The excremental stage of capitalism

In the third volume of *Capital*, Marx writes: 'As the capitalist mode of production extends, so also does the utilisation of the refuse left behind by production and consumption.' The waste first takes the form of heaps of iron filings, piles of rags, mounds of human excrement. Most of it amasses as unbearable pollution. 'In London, for example, they can do nothing better with the excrement produced by 4½ million people than pollute the Thames with it, at monstrous expense.'[374] As the mode develops and deepens, however, astute inventors will get to work 'so that materials that were previously unusable in their given form are converted into a form suitable for new production' – 'especially in chemistry, which discovers the useful properties of such waste products'.[375] Capital begins to eat its own refuse.

As for fossil capital, the moment might beckon when it also becomes post-fossil – 'post' as in carrying something forward rather than leaving it behind. An epiphenomenal loop would be placed on top of it. After two centuries of self-expanding value passing through the metamorphosis of fossil fuels into CO_2, we can now have the metamorphosis of CO_2 into practically any commodity, because chemistry has given us the transubstantiation of air into substance. Technologies other than DAC reuse waste. Indeed, the catalogue is filled with ideas: turning plant litter into biochar, waste from mining into fuel and concrete, crop residues into BECCS, shit from Los Angeles into fluid for the cavities. But DAC alone holds the promise of making the entire atmospheric cesspool of CO_2 directly available for commodity production – or, the melting of air into solid gold.

Can it ever work? This is capitalism at its most dazzlingly creative and disarmingly charming. And after all that has transpired over the past centuries, who can dismiss its conjuring powers? One of the productive forces that did most to revolutionise human metabolism in the twentieth century was, after all, a method for picking the fruits of the air: the Haber–Bosch process, foundation of the Green Revolution. But some non-negotiable laws of thermodynamics seem to stand in the way of a full closing of this circle. In the words of Marx, capital would have to learn 'how to overcome the practical frictions that arise in putting the theory into practice'.[376] Waste can become value only if the 'mechanical and chemical discoveries can be applied without increasing the price of commodities, and this is always the *sine qua non*'.[377] So far, the application of DAC always increases the price of commodities. For fossil capital to become post-fossil, the state might have to intervene so forcefully as to imperil the life of the former – which would, of course, defeat the whole purpose.

It is, by now, a platitude to say that the circular carbon economy and related notions have no *raison d'être* other than capital protection; but it is nevertheless true.[378] The point about post-fossil capital would be that it could still remain fossil at root. And if CO_2 were to become a resource, why try to keep it in check? 'Valuing the waste', Holly Jean Buck has remarked, 'normalises production of it.'[379] In this circle, the upper arc of capture would refuel the lower arc of ever-deeper extraction. But to get it going, the state would have to launch an attack on fossil fuels: and in this catch-22, the

circular carbon economy currently seems stuck. We cannot rule out that it might not somehow begin to develop. What we can rule out, as a matter of axiom, is that it would ever shift into reverse gear.

But then again the value-generating capacity of this imagined value might come precisely from its work in the imagination: all of these commodities are paraded as one more troop of phantoms. 'We sell promises', said van Straten.[380] Vodka from CO_2 is not being sold to lots of people who drink it. The value of it exists in the mental picture of capital as capable of conjuring up this stuff: so let us keep it going. One tactic for fossil capital to stay alive is to project a future image of itself as post-fossil. Here it also secretes fantasies about transcending the laws of matter and accumulating in vacuo, like an auxon, like 'a power springing forth from its own womb' (Marx).[381] Regardless of whether this ever becomes more than an image, our all-too-real planetary predicament is a result of the excrement from the metabolism of capital piling up not in the Thames, but in the atmosphere.

We might then take the metaphors of a Lackner and a Broecker seriously and conclude that capital began eating fossil fuels on a large scale in the early nineteenth century: and two centuries later, we are wading in the shit. The state of the Thames in the Victorian era was the result of the first meal. Once capital has devoured the planet, all of it – the atmosphere not least – becomes the Thames. The metabolic rift here extends not so much over space as over time. Likewise, Freud's theory of the deep association between accumulation and defecation should be interpreted temporally, historiographically: 'We know that the gold which the devil gives his paramours turns into excrement after his departure.'[382] Anal retention was never part of the capitalist character; rather, the sphincter is a missing muscle. The production of shit has known no bounds during these past two centuries, and nothing suggests that any can be internally activated.[383] It is, of course, this unbounded shit production that triggers the avalanches of climate breakdown.

To such eminently material realities can now be added the intense fascination with poo and sewage and waste in its different forms in the circles of bourgeois ideology production concerned with climate. One can add the circular vision of capital attaining eternal youth by eating its own faeces: 'The greening of capital is also its browning.'[384] Perhaps one can

also cite the fundamentally shitty quality of it all. Perhaps one can adduce the overwhelming sensation of living in a world of general entropic disorder, like Dadan in Emir Kusturica's *Black Cat, White Cat* when he falls into the outhouse.[385] All things considered, we seem to currently inhabit something like the excremental stage of capitalism. The Capitalocene is also the Excrementocene.[386]

Relations over forces

Negative emissions technologies are fettered in capitalist property relations. They have to generate value, in the form of credits or products, neither of which draw down CO_2. In the case of DAC, 'we face', Parenti has written, 'what Marx described as a contradiction between the forces of production and the relations of production. The social relations of capital are now holding back the full potential of some of the most promising technologies that modern science has yet invented.'[387] Just how promising DAC really is can, as we have seen, be questioned and doubted; but some potential it might have. And the relations hold it back. This, of course, is some distance away from the orthodox rendering of the contradiction: DAC is not a motor of history about to smash through capital and drive humanity into communism. We are here offered a lesson *in media res* of the primacy of the relations over the forces.

The historical sequence can then be crudely summed up: after having called forth productive forces that wreck the climate system, capitalist property relations are capturing another set of forces that could contribute to its stabilisation, in order to instead shore up those same relations and prolong the destruction to which they are prone. Here is, with Adorno, 'a simple reminder that the productive forces of technology are shackled and pushed in a very specific direction, and that the prevailing conditions prevent anything which might enable technology to break through this veil'. Instead of 'unswerving negation' – what negative emission technologies should be all about – we get one more way of 'sanctioning things as they are'.[388] Capital will not release these forces from 'the universal domination of mankind by exchange-value' and let them work for something to which no such value can attach: a stable climate for all, impossible to bring to the

market in a shining green bottle or white sneaker or, for that matter, the certificate of an offset.[389]

The primacy of relations runs along two axes: late technopower, in which energy and material for the forces are assembled through subordination of people, and late value form, in which they are put to work for the production of value. Combined, they give rise to questions such as: should we dedicate renewable energy to the manufacturing of synfuels and AIR Eau de Parfum? Or should we rather reserve the surplus of electricity on sunny and windy days for mineralisation (supposing that it works)? These are some moments in the dialectics of forces and relations, into which ideology, of course, enters at every point. It should be kept in mind that late value form has so far developed through sums of money absolutely nugatory compared to those poured into the ever-expanding extraction of fossil fuels. Fossil capital primarily seizes these forces *in utero* for their ideological services. What is technic is first and foremost psychic.

12

The Logic of the Magic

In developing negative emissions technologies, capitalism shows the undeniably clever and creative sides of itself. But these are also capitalism at its most stunted and superstitious. If a fundamental paradox of bourgeois modernity is the ever-increasing power to manipulate natural systems and the ever-decreasing capacity to influence social ones, then the entrepreneurs of this space are its most fervent priests.[1] They combine boundless technological voluntarism with bottomless resignation to political fate. A hundred little Elon Musks, they are working for 'a totally transformed future that will look very much like the present', in the words of Jesse Goldstein – or, as one of his informants divulges: 'We want to deliver a solution without changing the world.'[2] But they operate under a darkening sky and are cognisant of it, their confidence bound to a creeping despair about the state of the planet, moods alternating between highs and lows. There is also a distinctly metaphysical dimension to their project. Company names such as Living Carbon, Spiritus, Infinitree, Carbon Infinity give it away. In one of his rather more maniacal performances, at a gathering in 2023, Tito Jankowski of AirMiners summoned a congregant to the stage: 'I'm going to show you the carbon removal handshake,' he said, in a manner copied straight from a pastor asking for a testimony. He raised his right hand high towards the sky. He explained how the handshake works: open your hand in the air, grab the carbon, give a fist bump to your neighbour – and then 'never let it [the carbon] go'. He then had the whole congregation turning in the benches to the closest neighbour and repeating the ritual.[3]

What is at work here? It brings to mind Walter Benjamin's notes on capitalism as a 'purely cultic religion, perhaps the most extreme that ever existed. Within it, nothing has meaning that is not immediately related to the cult,' whose sole dogma, if there is one, he identifies as 'utilitarianism'. Whatever can be used must be used to make more money, as in the mandatory rituals of a sect. At the same time, capitalism is 'the expansion of despair, until despair becomes a religious state of the world in the hope that it will lead to salvation'. On this 'passage of the planet "Human" through the house of despair', there arises a new divinity: the 'superman'. He is there to allay 'anxieties, torments and disturbances'. He is the man of object control, 'the man who has arrived where he is without changing his ways; he is historical man who has grown up right through the sky.'[4] Right through the sky: the religious features of negative emissions technologies are manifold: the will to believe, the waiting for miracles, the heavenward gaze, the taking away of sin, even the ecstatic abrogation of law.

But the most salient supernatural feature is certainly magic. Here we should turn to Freud. Virtually all reflections on magic in modern technology are based on anthropological theories of the practice; but we are interested in its strictly psychic function, which so persistently presents itself in this field.[5] Freud first sketched a theory of magic and technology in *Totem and Taboo* and then returned to it in his lecture on 'The Question of a *Weltanschauung*'. In both, he offered pseudo-anthropological ruminations worth little attention, except for their illustrative power. 'In their struggle against the powers of the world around them', Freud writes of animist peoples of the deep past, 'their first weapon was *magic*, the earliest forerunner of the technology of today.'[6] Already here, he draws a line from the most primeval magic to the most modern marvels: the former foretokened the latter. How, then, did the magic begin? Freud thinks it originated in attempts to control the weather. The archetypal example is the making of rain: 'If I wish it to rain, I have only to do something that looks like rain or is reminiscent of rain' – script for the first magic ritual.[7] 'Rain is produced magically by imitating it or the clouds and storms which give rise to it, by "playing at rain", one might almost say.'[8] This might involve pouring out water or performing some other action that mimics the natural event the subjects wish to see. Practitioners of magic believe that they can

influence the external world through a projection of their mental picture of its desired state. Magic is mimetic but fully centred on the ego.[9]

Freud can then cut to the heart of the matter: magic 'reveals in the clearest and most unmistakable way an intention to impose the laws governing mental life upon real things'.[10] The principle that governs magic is '*the omnipotence of thought*'.[11] Practitioners cleave to 'the belief that the real events in the world take the course which our thinking seeks to impose on them'.[12] Magic is an idealistic way of relating to the world – it mistakes 'an ideal connection for a real one' – but even more importantly, it is inseparable from narcissism.[13] Magicians conflate the control they have (or think they have) over their own thoughts with a control over things. They evacuate external reality and fill it with their own selves, whose grandiosity can then be reflected in it. Magic is the over-valuation of one's own psychical acts – 'an essential component' of narcissism. It simulates engagement with reality while shying away from it and withdrawing into the hollow of the superman. Magic originates in people holding on to 'their unshakable confidence in the possibility of controlling the world and their inaccessibility to the experiences, so easily obtainable, which could teach them man's true position in the universe'.[14] Freud could here be writing about Lackner or Chichilnisky or McGinnis or Musk or most other characters in the saga of negative emissions technologies. But this negative magic is not a personal quirk: it is a systemic syndrome.

Magic arises as a potential out of the *differentia specifica* of human technology. Precisely because the architect builds his cell in the mind before he erects it in reality, he might succumb to magic when drawing it up, seduced by the omnipotence of his own thought. Under the capitalist mode of production, more specifically, contradictions might emerge that propel the ego to take this kind of flight. In the early twenty-first century, there is an absolute contradiction between capitalist property relations and the productive forces they have called forth on the one hand and the existing climate on Earth on the other; and people who cannot imagine a break with the former are pushed in the direction of magic. They want the rain to fall, without having to give up on the prevailing order. They cease to abide by the laws of reason. Someone like Elon Musk shows all the symptoms of this.

The total material dominance of capital elicits regression into idealistic and narcissistic magic. This is not to say that no negative emissions technology can ever come to operate in reality; as Freud makes clear, all modern technology has a magical element to it (which, logically, ought to mean a rising curve of narcissism). When it works, ‘control over the forces of Nature is unmistakable’.[15] Drebbel might have started off as a magician and charlatan, but submarines and DAC devices were eventually launched. Freud himself seems to think that weather control is close at hand. After the rain magic of the animists, at a later stage of civilisation, ‘processions will be made to a temple and prayers for rain will be addressed to the deity living in it. Finally, this religious technique will in its turn be given up and *attempts will be made to produce effects in the atmosphere which will lead to rain*.’[16]

The most advanced kind of technology seeks to exercise real control over the atmosphere: but it retains something of the magical within it. The omnipotence of thought survives in ostensibly ultramodern engineering of the climate; perhaps it even breaks through and takes over.[17] Reality principle and escape from reality are in constant tension in negative emissions technologies. Much of their operations so far can be seen as the *playing* at removal, each startup performing its own ritual of doing something that looks like it. A carbon copy of photosynthesis, DAC is perhaps the ultimate mimetic technology. If these ‘are not charms, they are at all events counter-charms, designed to ward off the expectations of disaster’.[18] Because of their admixture with science, some might have effect. But there is also a lingering sense of disbelief: is anything of this for real? Or will it just dissolve like a mirage in the desert? If so, how then do we make it rain?

PART III

The Future Is the Termination Shock

13

God from the Machine

Imagine that global heating is left untreated. This does not require extraordinary feats of the imagination. It is rather easy to picture the storm continuing to progress as it has for years now – but for how long, before something larger breaks? One day, it might reach a pitch of intensity that makes the inert order of capitalist society snap. People in charge could suffer a panic attack: something has to be done, immediately, to get this situation under control. We can imagine the activation of a tipping point having this effect – perhaps an ice shelf too large to ignore breaks off, or the AMOC goes down, or the permafrost sends clouds of methane billowing over the north, or, come to think of it, the Amazon bursts into flames.[1] But it could also be a more localised avalanche that pushes the 'policymakers' over the edge. Imagine Los Angeles is consumed by a firestorm larger than that of January 2025, as in one of the many memorable scenes in Markley's *The Deluge*.[2] Or Miami is lost to the waves after a hurricane of indelible force. The collected corpus of climate fiction plus science contains no small number of scenarios, and ripples and cascades may sally forth from each: the loss of Miami induces a financial meltdown.[3] Or – nothing can be ruled out – the ever-expanding circles of climate suffering finally usher in a revolutionary situation and send the spectre of capital destruction marching through the streets and setting off panic in the palaces. Or the accretion of impacts simply crosses some nodal line. Any number of combinations of events may bring it about – also because of its subjective dimension: no one can tell beforehand just what disaster will cause a fit of terror in high places. All that is needed is for the heating to keep progressing and then

something will, sooner or later, with the highest likelihood, create what we might call a *control emergency*.

Now emergency is old news in climate change. From Canada to Korea, authorities have declared ‘states of emergency’ when some province or other has been destroyed by fire or flood.[4] With a different inflection, movements circling the globe at the end of the 2010s demanded official declarations of a ‘climate emergency’; in an achievement of sorts, the Oxford Dictionary picked this term as the word of the year for 2019. Its use had jumped by 10,796 per cent over one single year, testimony to the lexical influence of the Greta Thunberg generation.[5] When she and her comrades spoke of ‘emergency’, what they meant was, to put it crudely, that things were now so bad that business-as-usual must be broken. They called for a rupture with the status quo. A control emergency would have another logic, more akin to a branch of government reacting to disaster, but projecting that reaction to the planetary scale. Here the purpose would be to restore and conserve the status quo, minus the destructive heat – to get back to the way things were before the bad tidings.[6] This might be reminiscent of the ‘state of exception’ instituted by a sovereign from the pages of a Schmitt or an Agamben, but instead of sliding down that theoretical slope, let us stay with a basic observation out of one of the *Nature* journals: ‘A historical perspective on states of emergency reveals the appropriation of the concept by capitalist and colonial states to repress class struggles and quell popular mobilisations.’[7] (All a Marxist needs to read these days is *Nature* and its sister journals.)[8] A control emergency, in other words, is one in which *dominant classes experience an imminent loss of control over society* due, in this case, to some events in the realm of climate *and look around for an instrument by which to reestablish and prop up control before it is fully lost*. What might they find?

Negative emissions technologies would not be suitable at this moment. The scientists proposing lamps over the rainforest had the temerity of calling it ‘an emergency solution if society relies heavily on carbon removal to adjust the Earth’s climate’; but there is nothing to suggest that it would work at the speed required.[9] DAC would be a more serious contender. From the one modelling of emergency DAC to date, we learn that an acute climate crisis – so perceived from on high – would rally people to the mission of containing it. But this would happen ‘in ways that reinforce

existing interest groups such as industrial producers', so that 'big emitting industrial practices could remain in place'; forever at peace with them, governments would be so agitated as to pay almost anything for what must now be a truly quick fix.[10] They would gladly print money for DAC. A no-holds-barred wartime-like mobilisation could commence in 2025. Nevertheless, the machines would take time to construct, and time to draw down CO_2, and time to cut actual temperatures, so that by 2100 the global average would be between 0.1°C and 0.2°C lower than without this whole effort – one paltry tenth or fifth of a degree Celsius. (On the assumption that DAC capacity hits close to 30 gigatonnes by the end of the century.)[11] In a rapidly warming world, few would notice this as even a breath of fresh air. DAC might be attractive because it comes without 'intrusive policy interventions, such as requiring existing firms to transform their production methods', but it would operate too much like a gradualist machine in the moment of catastrophe.[12] When nature is at its most Hegelian–Leninian, it cannot be brought back to order with a slowly ticking clock. Whatever negative emissions technologies can possibly accomplish, it would take decades, perhaps more than a century, to empty the atmosphere and cool the earth measurably; but in an all-out control emergency, there would be no patience for such a long wait.

In the warehouse of technologies, only one has a known capacity to give instant relief. Block incoming sunlight. Shoot or spray soot into the stratosphere. Erect a parasol around the earth, so that less heat from the sun makes it here. Geoengineering alone can cut temperatures from one month to the next; if temperatures are rising and spiralling uncontrollably, geoengineering and geoengineering alone has the potential to subdue them. Temperatures are a function of the amount of solar radiation striking the surface of the earth and the amount trapped in its atmosphere as it tries to depart. Positive and negative emissions change the latter variable – the heat that is held up in transit – while 'solar radiation management', as the term indicates, tinkers only with the former. It is 'not anti-CO_2', as David Keith and his fellow advocates readily admit.[13] It leaves CO_2 and other greenhouse gases in peace. Bypassing the proximate drivers of global heating, it aims for a background condition that never had any role in fomenting it: the luminosity of the sun itself, as seen from Earth. Geoengineering alone has the power to break the causal link between

temperatures on the one hand and atmospheric concentrations of CO_2 and its lesser peer gases on the other. Deploy it with sufficient pressure and perseverance and these concentrations may well continue to rise without temperatures doing so – something truly new under the sun, a change of the basic equation of climate politics. Or so it would indeed seem. Geoengineering would offer at least as much love and harmony to 'existing interest groups' – the dominant classes themselves, that is – as would DAC; but it would need more like a week than a century to knock out one tenth of a degree Celsius. In a control emergency, it would shine like a magical sword.[14]

Iron Dome for the planet

If removal would be toothless in such a situation, so would mitigation. An instantaneous eradication of all emissions in the world on a Monday morning would not lower the heat. It would merely prevent it from getting worse. But if positive feedback mechanisms are already in motion – the permafrost thawing, the Amazon burning … – temperatures may still continue to soar, even after the most ultra-revolutionary shutdown of the sources. Moreover, if a tipping point comes so close as to be clearly visible, it could already be too late to avoid its activation by means of emissions cuts, because the system may be impelled by its own inner dynamic. Once it has started falling towards an alternative basin of attraction, mitigation is powerless. Lenton has compared this to someone jumping from the edge of a cliff. Mitigation has arrived too late on the scene – the person cannot be stopped – but during the seconds when she floats in the air, geoengineering might supply a counterforce that blows her back to the cliff, before gravitation takes her to the bottom of the basin.[15] Perhaps. The power of geoengineering to reverse climate change is constrained by all the usual factors. It differs from removal only by the speed it can attain. Yet it might be the contrast with mitigation that is most fateful, because it seems to imply that when heating has progressed far enough, *not even the most revolutionary onslaught on fossil capital can relieve climate suffering*. Here might be the ultimate tragedy of overshoot: at a certain point of too-lateness, *anyone* who would want to slam the brakes on temperatures would

have to resort to geoengineering. Physics admits no other recourse. It might not work well or work at all; but when it is sufficiently too late, one can be positive about removal and mitigation being impotent in the heat of the moment.

Geoengineering, in other words, could be the choice not only of the dominant classes. The strongest preference for it might come from the victims of the heating. Storylines have been spun around them rising up against the sunlight. Some have imagined subaltern states guarding their populations from annihilation and launching geoengineering, in disregard or even open defiance of imperial powers. Implicit in that alternative scenario are some of the most difficult questions of climate politics when it's too late: could progressive forces ever avail themselves of geoengineering? Might this technology be tamed for the purposes of a liberating survival? Should we aim to seize the means of solar radiation management? We shall return to these questions in the next and final part of this book; here we shall stick with the control emergency as the point of departure. We shall argue that geoengineering is far more likely to be done from above than from below. Indeed, if the world remains recognisably similar to the present – barring a world revolution, that is – it seems nearly inconceivable that this project would be run from anywhere else than the highest pinnacle of capitalist state power. We shall examine its identity and interests later. For now, we can expect dominant classes to be the first to scramble for geoengineering for two reasons, one tautological and one empirical. Dominant classes are defined by and constituted through their control over the means of production – including means of climate production, if any such exist. It is axiomatically more plausible that geoengineering is initiated by representatives of capital than by an indigenous nation whose lands have been burned to ashes or by villagers threatened by glacier lake outburst floods. The most advanced technologies are in the hands of the former not the latter.

Second, a control emergency ending with the deployment of geoengineering would fit only too well into the modus operandi of twenty-first-century capitalist society. When a crisis breaks out, it is never treated below the level of symptoms. The financial crash of 2008 was papered over with trillions of dollars from central banks. Dominant classes were in a state of panic after Lehman Brothers and swiftly corralled the necessary funds for bailouts and other measures to bring things under control, without

dealing with the underlying causes of instability, rather left to fester and mutate. In early 2020, another exigency exploded in their faces, and the reflexive reaction was to conjure up a technology with immediate effect: apart from the lockdowns, a vaccine. Covid-19 could have been an occasion to deal with the drivers of zoonotic spillover, notably tropical deforestation, but nothing was done to rein it in (in fact, logging soared to new heights during the pandemic).[16] Whenever migrants would try to cross into the EU or the US in ‘waves’, as they were referred to, the invariable response was further fortification of the borders. Bring out the patrols, the surveillance, the walls. The misery driving people onto boats and treks was, as a matter of course, never addressed. Not the least paradigmatically, when the chronic hyper-crisis in the Gaza Strip erupted into open conflict and the resistance fired projectiles towards the ethnically cleansed homeland, a first response was to switch on the Iron Dome – an advanced technological system for detecting and intercepting rockets in the troposphere, plucking them like fruits fizzing in the air – followed by the whole machinery of kinetic superpower for stomping the Palestinians back into the ground. The occupation itself became more entrenched every passing year.

Examples of this logic could be multiplied on end. In each mentioned, we can discern something approaching a control emergency: a stress factor that must be managed; little time to lose; a balance of forces skewed so heavily in favour of the dominant classes that they can pick the instrument most solicitous of the status quo. Twenty-first-century capitalist society appears constitutionally incapable of solving any problem. All it can do is to expunge symptoms. Perhaps capitalism has never been capable of correcting its own manners; but there have been times when the balance of forces compelled it to accept the shutdown of at least some root causes – decolonisation in the 1970s being one of the last cases. Because it now succeeds to excess, it keeps producing symptoms of crisis and stays unqualified for anything other than their most superficial treatment. In its excremental stage, capitalism is so bloated from victory, so unable to exercise any retention or restraint that it swims from one pool of its own shit into another and has to design new hazmat suits to keep going. Geoengineering would just be the latest, arguably the most all-embracing model. Where muscular adaptationism is a lesser strategy for repelling symptoms, geoengineering would jump to the highest possible scale and target the total symptom of heat. In the process, it might well, as we shall

see, produce novel symptoms, in more senses than one. It is particularly liable to be implemented because of its congeniality to repression, the most characteristic response to challenges to the prevailing order; again, as we shall see, in more senses than one. It would slot the climate problem into the standard-operating high-tech procedures of contemporary capitalism. This, of course, is why geoengineering is the polar opposite of Leninist politics: a desperate and blanket attempt to take down the symptom rather than a desperate and precise attempt to take down the cause.

On this front of climate politics, we are thus likely to confront geoengineering as a method for palliation. It has been sitting in the back of the consciousness of climate politics for some time, like an Iron Dome to be rolled out if the fire becomes unbearable. In 2006, Paul Crutzen published an editorial in *Climatic Change* that famously broke the taboo on the topic.[17] The imperative then remained structural in nature. It was not so much shrill sponsorship that pushed geoengineering to the fore over the next two decades. Rather, this option gained force for every year of unrestrained business-as-usual and exacerbated impacts. There was a sense that every season of disaster brought it one step closer to the arena: how many more heatwaves or hurricanes, droughts or deluges before someone called it up? Geoengineering was a – the – *deus ex machina* waiting in the wings. And fewer than two decades after Crutzen's editorial, it made something of a leap out into the open. It reached the phase of startup companies.

14

An Idea with Time on Its Side

It was not the underprivileged who took the initiative. It was one Luke Iseman, merchant of hardware and software, founder of multiple companies, former director of a ‘tech incubator’, builder of art installations for the Burning Man festival. Iseman had read Neil Stephenson’s cli-fi novel *Termination Shock*, in which a rogue Texas billionaire motivated by financial self-interest and an outsized saviour complex embarks on a mission to geoengineer the climate. In the book, he handpicks a small group of wealthy cities and countries to back his project, but the whole enterprise comes undone when uninvited big players start meddling with it and geopolitics makes its entry. ‘I don’t deny that things have gotten a little out of hand,’ the billionaire remarks while in hiding from a coordinated drone attack on ‘Pina2bo’, his geoengineering facility in the Chihuahuan Desert. ‘But you gotta start somewhere.’[1] Iseman came away from the novel convinced that here was a good idea he needed to spend his time and energy on.[2] ‘I was like, “I think I’m missing something. It can’t be this easy,”’ he explained the revelation to *Time*. ‘Turns out it is.’[3]

Iseman looped in his longtime friend and business partner Andrew Song, and in 2022, the two young Californian entrepreneurs started an outfit charmingly named ‘Make Sunsets’ – just how charmingly, we shall soon see. They sold what they called ‘cooling credits’. Their website demanded no more than ten dollars. For every purchase, Make Sunsets would blow one gram of sulphur dioxide into a weather balloon, add enough helium to make it levitate and let it ascend peacefully into the stratosphere. Under the increasing pressure at such altitudes, the balloon would burst and the sulphur disperse. The tiny particles would intercept some of the sun rays.

The rays would bounce back into space. Every gram of sulphur would thus counteract the warming from one tonne of CO_2, or so the duo claimed. ‘Think of it as applying sunscreen for our planet!’, their website exclaimed.[4] That particular metaphor originated with ChatGPT, after Song asked it how ‘he might explain geoengineering to a five-year-old’.[5]

Make Sunsets staged all the typical performances of overshoot ideology: ‘What we have done has not worked. And we need to try many more broad approaches,’ Iseman edified a reporter who came to witness one of the balloon launches.[6] While emissions cuts were necessary – granted – it would be a ‘tough ask for many organisations and individuals’. Such pessimism now extended to removals; like renewables, they ‘hold promise’ but would ‘take time we don’t have’.[7] Prolonged use of fossil fuels was par for the course, because ‘most humans will chose [*sic*] the cheapest and convenient option’.[8] Or more brutally: ‘There’s no realistic path over the next 50 years in which we decarbonise without literally letting over a billion people die by removing their ability to eat and power things.’[9] By comparison, lofting sulphur into the atmosphere would be ‘an effective solution’ – ‘cost-effective. Inexpensive.’[10] This, of course, was music to the ears of a particular tribe. One customer of cooling credits thanked the company for creating ‘a small way I can help with a seemly [*sic*] very large problem! For what it’s worth $200 to offset 20 tons of CO_2 is a great win!’[11] This particular client was a CEO himself, namely of a company running a digital platform on which people could safely store their most private and valuable secrets.[12]

Through these familiar mannerisms, overshoot ideology came packaged in a peculiarly Californian business ethos, in which unhinged entrepreneurialism in rebellion against rules and expertise was elevated to a cultural form. Neither Iseman nor Song had any scientific training to speak of, but self-confidence and marketing acumen to spare. As profiled in several major newspapers and magazines, they gave off something of a Beavis and Butthead vibe. They assembled their balloons with components from Home Depot and Walmart. They cooked up their first brews of sulphur dioxide all by themselves, learning from YouTube videos, burning sulphur-based fungicides in pressure cookers in hotel rooms or on disposable charcoal grills in public parking lots. They regularly gassed themselves and onlookers in clouds of sulphur dioxide (an irritant gas, dangerous in high

concentrations). They eagerly showed off these experiments to the media, seemingly revelling in the provocative and slipshod nature of the whole thing.[13]

Iseman and Song operated in a legal grey zone and seemed to thrive there. Their first tests took place south of the border, unbeknownst to the Mexican government – until it was alerted and, chagrined by this breach of national sovereignty, banned geoengineering tests altogether.[14] Make Sunsets then moved back to the US, where experiments of this sort required only a formal notification to – not approval from – authorities.[15] This murkiness was of a piece with the spirit of the venture. On their own admission, Iseman and Song had no idea what happened to their first balloons, because there was no monitoring equipment to follow their fates.[16] Whatever might have transpired, the sulphur particles would have drifted down to Earth after a stay that could not, as we shall soon see, have lasted for very long. It was physically impossible for them to counteract CO_2 of even the smallest amount. The soot would be blown out of the atmosphere before Iseman and Song could say poop. If ever there were bullshit credits carted off to the market, these were the ones.

Iseman, as it happened, was no stranger to shit. His earlier ventures included creating an unlicensed shipping container community in the Bay Area, in which the inhabitants composted their human excrements on site, until the neighbours started complaining about the mess and the municipality forced them to close down. He often spent time on a houseboat in London, where, in the absence of a toilet, he resorted to burying his waste in public parks.[17] It now becomes very tempting to read Iseman as another prophet of the excremental stage; unlike Lackner, however, his solution did not consist in any actual removal of the waste. Geoengineering would rather keep it in the public arena but sprinkle some particles over it to cover the smell, as it were.

The prophetic style of this particular duo was also more populist and prankish than anything found in the removal space. In 2024, Make Sunsets launched a number of new products on its website. One consisted of ninety-nine ‘limited edition’ pieces cut out from the first balloon filled with sulphur and dispatched into the atmosphere from US soil; if you bought one for ninety-nine dollars, you would ‘own a piece of history’ – prophecy as merch.[18] (This product was an apparent reference to the famous German

anti-war pop song ‘99 Luftballons’, in which a general sends up fighter jets to shoot down ninety-nine innocent balloons and as a result unleashes a cataclysmic world war). Then there was ‘Big Bertha’, a complete kit for sending sulphur into the stratosphere, including a weather balloon, a satellite tracker, a starter bag of sulphur: ‘We think everyone should be able to Cool Earth.’[19] For those who did not have $500 to dole out on the complete kit, there was a cheaper alternative in store. A mere twenty bucks would buy you the ‘Tiny Party Pack’, a bag of latex balloons and some calcium carbonate (another reflexive agent). This was ‘unlikely to make it to the stratosphere, but you’re doing it for fun and everyone loves balloons’.[20] Iseman and Song themselves demonstrated the party balloon trick to children at various events, hoping to inspire a new generation of geoengineers.[21] ‘We joke slash not joke that this is partly a company and partly a cult,’ the former let slip.[22]

Any serious analysis of this stuff would risk coming across as redundantly heavy and humourless, but it really should be considered a sign of bourgeois degeneracy: this was climate politics holding a selfie stick. It was climate politics – efforts, that is, to address a rather significant actual problem – as clownery. In all its flagrant incapacity and incontinence, capitalism reflected back onto itself the character of someone trying to deal with the problem as a way to go viral on Instagram, or at least get a few clicks. Climate politics here self-avowedly operated in the register of amusement, and amusement should, we know from Adorno and Horkheimer, be taken deadly seriously: it ‘always reveals the influence of business, the sales talk, the quack’s spiel. But the original affinity of business and amusement is shown in the latter’s specific significance: to defend society. To be pleased means to say Yes.’ To be in on the joke of Make Sunsets means learning ‘to forget suffering even where it is shown’ and flee ‘from the last remaining thought of resistance’.[23]

The vulgarity of Iseman and Song was too much for the true friends of geoengineering; every scientist with some self-respect – Keith very much included – took an embarrassed distance from it.[24] That did not prevent Make Sunsets from collecting funds from the usual Silicon Valley corners, surplus capital always ready to take a bait. Nor did it stop the company from selling – as of March 2025 – 124,600 of its first-rate specimens of bullshit credits and sending 144 sulphur-filled balloons into the

stratosphere.[25] Nor did it erase the historical significance of the episode. It was Iseman and Song who conducted *the first real-world experiments in geoengineering* – a trial balloon to the letter.[26] The idea now entered the atmosphere as particles, if only so evanescently. Unless the story of geoengineering stops in 2025, we will have to look back upon Iseman and Song as trailblazers. They set a precedent. 'This is an emergency,' Iseman insisted when queried on the desirability of what he was doing. 'I'm not going to sit around and not take action because the responsible adults think there might be geopolitical consequences.'[27] The prophet and the clown, he possessed a certain wisdom. 'If, with no strings attached, some oil company gave me 10 billion dollars and said, "quietly do deployment to half a degree Celsius", I'd be lying if I said I wouldn't do it.'[28]

Satan and the state of Israel enter the race

2022 was not only the year of the greatest profits ever made by primitive fossil capital. It was also, coincidentally – no sponsorship from oil companies detected; the imperative still structural in nature – the year of the first experiments in geoengineering. It was in April 2022 that Iseman and Song snuck into Mexico for their inaugural release. Then in September, men (as in removal, always the men) with actual scientific credentials undertook the second recorded experiment, on the other side of the Atlantic, in the green and pleasant lands of Buckinghamshire. Led by one Andrew Lockley, the team hung a basketball-sized balloon loaded with sulphur dioxide under a bigger balloon, towed it into the stratosphere and released it to a carefully tracked destiny: the smaller item popped. The payload was verifiably dispersed at an altitude of twenty-four kilometres. The researchers christened the project 'Stratospheric Aerosol Transport and Nucleation', or SATAN for acronym.[29] It was not immediately clear if this was another bad joke, an incongruously transparent parapraxis or some other category of speech act; Buckinghamshire did not generate the same spectacle as California. SATAN announced its name only once and then withdrew into silence (as of this writing). No credits were sold. But before 2022 came to an end, the two historical cores of fossil capital, the United

Kingdom and the United States, had thereby each produced an experiment in geoengineering.

Neither was as consequential as the next. On 14 February 2024, the genocide in Gaza was in full swing.[30] On this day, the *Wall Street Journal*, long priding itself for its access to the secrets of Middle Eastern politics, reported on a third experiment underway. 'In Israel, a startup called Stardust Solutions has begun testing a system to disperse a cloud of tiny reflective particles about 60,000 feet [18 kilometres] in altitude,' still within the lower reaches of the stratosphere.[31] Here no childish balloons were brought into play. In the words of the reporter, 'they are doing aerial testing of an idea called solar radiation management, also known as stratospheric aerosol injection, by basically flying really high in an airplane, releasing reflective particles' – a first under the sun.[32] If the *Wall Street Journal* got it right, somewhere in the skies above historical Palestine, just as thousands of children and women and men were slaughtered on the ground, as they slept in their tents or queued up for flour or ran through the dusty alleys of their camps, an aircraft rose to eject soot in an exercise in geoengineering. That would have been quite the baptism.

Stardust, however, operated in a manner exactly opposite to that of Make Sunsets: behind a tight curtain of secrecy. The company would not 'disclose the composition of the proprietary particles' to the *Journal*.[33] It posted nothing on Instagram. But some morsels of information could be pulled out. The CEO of Stardust was one Yanai Yedvab, formerly the deputy chief scientist of the Israel Atomic Energy Commission, the organ responsible for the nuclear activities of that state, famously including a semi-secret depot of A-bombs.[34] Yedvab's old boss at the commission was a cofounder.[35] Stardust was talkative enough to say that the solution it brought to the world is 'the only one that can lower global temperatures within a few years', in addition to being 'a thousand times more cost-effective than any alternative'.[36] It claimed to be developing the technology in anticipation of demand from governments.[37] Its capital came from an entity called Awz Ventures.[38] Awz Ventures was based in a tower on Menachem Begin Street in Tel Aviv (with a second office in Toronto).[39] It ran a business accelerator to fund incipient technologies and support recipients' 'journey from concept to product to market'; it had a special ace up its sleeve.[40] The 'unparalleled deal flow stems from our partners and advisors' ties to the Israeli security

technology ecosystem' – an ecosystem of a kind, centred on the Ministry of Defence and encompassing 'Mossad, Shin Bet, and elite technology units like 8200', the latter worthy of note for its activities on the ground in Gaza.[41] Shortly after the onset of the genocide, the founder of Awz Ventures, Yaron Ashkenazi, described his company as

> providing Israel – and the world – with the technological tools to stop these evil terrorists in their tracks … At Awz Ventures, we are discovering and creating the next generation of technologies that can help Israel and the righteous side of the world. We are partnering with security and intelligence agencies and developing, from inception, companies to help solve the problems for which we don't yet have solutions – which will protect democracies and nations.[42]

Three sons of these partners headed the accelerator that funded Stardust. One was Ashkenazi himself: he had spent ten years running the security detail of the prime minister of the occupation.[43] One had served as the top boss of its police force.[44] One had directed the prime minister's office for technological innovation; after 7 October, he also threw himself into another outfit, called the Israel Defense Fund.[45] The purpose of this fund was to patch up the walls through which the Palestinian resistance smashed on that day. 'Although Israel has one of the most advanced militaries in the world and is separated from Gaza by a highly sophisticated technological barrier, it was not enough' to withstand the attack; and so it was necessary to 'address technological gaps in border security, command and control, and urban warfare'.[46] If Toufan al-Aqsa represented the worst control emergency in the history of the Zionist enterprise, some of the more generally applicable lessons might have been brought to the climate front. *Relations of domination are defended through the deployment of technological force for the suppression of their own symptoms*. Among the advisors of Awz Venture's accelerator was the former commander of the elite Unit 8200 of the IDF.[47] It was his successor who conceived of the automated machines for processing enormous amounts of data about Palestinian civilians – the engine of the 'mass assassination factory' working at maximum capacity in Gaza to undo 7 October, while the aeroplanes of Stardust circled somewhere above.[48]

But Stardust was far from an exclusively Israeli affair. The team of Awz Ventures also included one former director of the CIA, one former director of MI5, one former associate deputy director of the FBI and one former

prime minister of Canada, among other luminaries.[49] Stardust itself employed twenty chemists, physicists, aviation experts and other kinds of scientists.[50] It pulled off a major coup in early May 2024, when it recruited Janos Pasztor as ‘an independent consultant’. This man had a claim to being the world’s leading expert on one particular aspect of geoengineering: how it ought to be governed. Few had thought as much or spoken as prominently on precisely the governance question; ‘the real challenges pertain to ethics’, Pasztor would write in *Science*.[51] Overshoot drove geoengineering to the top of the agenda. Problems then arose. ‘Who would control the global thermostat? Who would decide whether or not one or more actors could attempt a large-scale outdoor experiment to reflect sunlight back into space, based on whose authority or legitimacy, using whose data, and under what conditions?’[52] Soon after writing these words, when the genocide was underway, Pasztor resolved to join Stardust. He claimed to have overcome his initial ‘reluctance’ to do so ‘given the ongoing war in Gaza’ because of the ‘urgency and importance’ of the work this company was doing.[53]

On 10 September 2024, the self-styled conscience of geoengineering released a report about the activities of his employers. This would have happened just as the sun rose on three enormous craters in the sand of al-Mawasi, the ‘humanitarian zone’ in which hundreds of thousands of displaced Palestinians had been crammed: overnight, fighter jets struck the camp and set tents on fire with sleeping families inside them – entire families that disappeared into the sand, together with their mattresses and blankets, in the latest in the endless series of massacres, this one killing around forty.[54] Pasztor was unruffled. He confirmed that Stardust had indeed conducted ‘unannounced low-altitude flights’.[55] The company had ‘designed, manufactured and tested an engineered particle’ by means of unspecified aircraft. He considered it a success story: ‘Stardust has made significant progress in addressing the primary technical challenges’ of stratospheric aerosol injection; and there was more to come. Soon his colleagues would upgrade ‘the prototype airborne dispersion system to an operational level’ and validate their capabilities ‘in high-altitude aerial monitoring experiments’.[56] In the entity from which Stardust took off, only one institution could possibly supply the jets required for such tests: the Israeli Air Force.

Pasztor could still see nothing wrong with it. He justified the endeavour with the usual circumlocutions. ‘Global emissions continue to rise’; overshoot is on track to hit almost 3°C; ‘the current geopolitical/geo-economic situation is not conducive to substantially altering these trends for the better’, and so one must go with the flow.[57] A private company like Stardust would be well placed to ‘research and develop aerosols’ and ‘the necessary aircraft’ and ‘the spraying mechanisms; perhaps even to implement the whole process of deployment on delegation from governments’, although Pasztor maintained that the investors – in this case, Awz Ventures – envisioned profits from a technology that would ultimately have to be acquired by some friendly state.[58] He thereby wrote the baptismal certificate. The font was set up by the genocidal regime. Thus the idea of geoengineering was first brought into the material world.

There would have been riots

A long period of incubation led up to this point. Indeed, if we are to believe the speculations of Freud, weather control, in the most generic sense, was the first magic technology humanity aspired to. Concrete techniques for manipulating the amount of incoming sunlight were studied – on paper, on screen – for half a century before the first experiments. Much of this research happened inside military apparatuses: the link to nuclear weapons in the Stardust venture was anything but coincidental. Nor was that to imperial violence. We shall examine this prehistory of geoengineering below and come across several intersections with the ultimate weapon of mass destruction; before the 2020s, however, this was all a theoretical exercise. It did not have a high impact factor. It was, rather, considered a fringe pursuit. After years in the labs and the corridors, Keith and two of his colleagues published a paper oozing with frustration and self-pity: no one cared for their work. They scraped by on funds from a few private donors, as governments were united in their indifference. Not only did no politicians champion geoengineering, no one ‘advanced a comprehensive, fully developed research plan for public consideration’.[59] But barely had this complaint been published before the dreams of Keith and his cohort began to come true.

The state apparatus of the US was the first to gravitate towards geoengineering – or at least, as a necessary preamble, comprehensive research into it. In 2020, Congress ordered the National Oceanic and Atmospheric Administration to start looking into the chemistry of the operation. Weather balloons were dispatched to gather basic data on sulphate particles: how they fly in the stratosphere, in what sizes and concentrations, for how long. The Administration escalated the research in early 2023, by launching 'the largest stratospheric aircraft campaign' in decades – possibly ever – from Houston, of all places; a modified bomber flew high into the stratosphere to track the behaviour of the particles.[60] None were released. This was a passive study, tasting the soup before spicing it. In the year following, the government of the UK – second pillar of the geoengineering enterprise – sought to catch up by announcing funding for outdoor experiments.[61]

This ball was evidently rolling. Another fillip came in early 2021, in the form of a report from the National Academies of Sciences, Engineering, and Medicine, or NASEM, the highest scientific institution in the US. A 300-page dossier, *Reflecting Sunlight* investigated the option in more detail than ever before. It stopped short of recommending deployment, but ardently advised – no small thing – a well-endowed national research programme to learn more about what could be done.[62] No major scientific body in the world had made a similar call before.[63] To Keith, it was 'thrilling' news.[64] The chair of NASEM explained that 'until recently, I thought it was too risky, but slow progress on cutting emissions has increased motivation to understand techniques at the margins like solar geoengineering'.[65] The Biden administration took the advice to heart: in 2022, the White House authorised a 'five-year plan' for coordinated federal research on the technology.[66] It would enlighten the state through model runs, satellite measurements, outdoor experiments, flights with the most advanced aircraft.[67] Outside government halls, the Environmental Defense Fund – the quintessential green capitalist NGO in the US – announced its own in-house research programme, validating the pursuit with the imprimatur of environmentalism lite.[68] A vocal minority of scientists were moving in the same direction. They were led by the grand old man of American climate science in general and its anti-gradualist wing in particular: James Hansen.

An apparent majority freaked out. In late 2021, dozens of scientists reacted to the signals coming from the US with a call for an 'international non-use agreement', a moratorium to force the genie back into the bottle. Governments should prohibit their research agencies from funding the development of geoengineering technologies, ban outdoor experiments – this was written months before the premier of Make Sunsets – refuse to grant patents, commit to not deploy and make sure the option does not enter the *carte de jour* presented by institutions like the IPCC.[69] Many hundreds of scientists subsequently signed the letter.[70] But then the opposite camp responded in kind: a petition for revving the research engine. No aggressive action has been forthcoming; 2°C is a lost cause; tipping points are about to be crossed; removal is too hard to scale up to be sufficient on its own: there is no alternative. (Despite the hint to a whole appendix of caveats.) Sixty scientists put their names to this letter, a much smaller band, which, apart from Keith and the other usual suspects, included Hansen.[71] He elaborated on his reasons, in a characteristic synthesis of palaeoclimatic and fresh observations: the ongoing overshoot is one touch away from setting off a cascade of avalanches. The IPCC continues to uphold the fallacies of gradualism – including by crude 'censorship' – and to ignore the evidence for non-linear collapse of the ice sheets in particular; we could have twenty-five metres of sea level rise within a century or two.[72] Against this rush of disaster, only geoengineering can have any real puissance.[73]

The case was strong enough to warrant a special report from UNEP, depicting the incoming control emergency and calling for a 'global body' of scientists – a second IPCC – to evaluate the option.[74] The already existing IPCC began to engage with geoengineering in its cycle of reports from the early 2020s.[75] The European Commission added its voice to the choir calling for an international research effort, as did a few social scientists working on the subject from a position on the left.[76] But on the left, no one was more influential than Kim Stanley Robinson. As we have already seen in one instance, this nonpareil author of socialist sci-fi in the 2010s, the inheritor of the mantle of Ursula K. Le Guin, was deeply fascinated by what humans might possibly do with technology in a hotter world. With *The Ministry for the Future*, published in 2020, he produced the biggest cli-fi novel to date. It might have done more than any scientific report to implant the idea in a broader public. *The Ministry* advanced a subaltern, utopian

narrative of geoengineering: it is the victims of the breakdown that deploy the technology to survive and get free.[77]

A heatwave kills 20 million people in a fortnight in India. In the first, unforgettable chapter of *The Ministry*, Robinson describes with harrowingly credible realism how the electricity goes out in one village and AC systems break down and people seeking refuge from 'the blazing furnace' roast on rooftops or boil in a nearby lake.[78] The world's most populous country cannot take it anymore. The government orders a fleet of planes to circle through the stratosphere and pump out plumes of soot so as to form a sunshade thin but potent enough to slash the average temperature on Earth by three degrees in five years. The Indian population is spared more carbon holocausts. After half a decade of round-the-clock soot injection, the flights are discontinued, but – a questionable scenario, as we shall see – temperatures only gradually, slowly creep back to prior levels.[79] The respite is a feat of humanitarian intervention. Moreover, it joins the march of what is in effect a world revolution, by which fossil capital is consigned to history and something like ecological socialism saves a future for humanity.

If it was a Marxist who wrote the most gripping story of geoengineering in literature, however, it was the class enemy who moved ahead in the real world. Primitive fossil capital delicately midwifed the research at its earliest stages, part of the prehistory to which we shall return, and in the late 2010s and early '20s, the familiar faces of digital and financial capital – Gates, Bezos, George Soros, Dustin Muskowitz – threw their weight behind it, with such zest as to prompt *Time* to run a piece on 'Why Billionaires Are Obsessed with Blocking Out the Sun'.[80] The magazine took a sneak peek into the souls of such men. 'Addressing climate change', it noted, 'is going to take a truly gargantuan global effort.' There will have to be

> fundamental changes around what and how we consume – an understanding that society can't simply exist as a project to extract ever-greater quantities of resources without, eventually, hitting some sort of wall. If your life story involved working really hard on some stuff in your 20s, and then it [is] paying off so substantially that you're able to spend the rest of your life working on passion projects while everyone around you tells you what an awesome, cool genius you are, you're probably not, on a fundamental level, too excited about some sort of society-level change. In your experience, things have worked out really well, so therefore the thing we've got going right now is probably pretty good. But also this climate change stuff is definitively not-good. What to do? Solar geoengineering can seem like an answer to that question.[81]

With this paragraph, the number one mainstream magazine outlined the rudiments of a Freudo-Marxist theory of geoengineering: this technology speaks to the psychic needs of the dominant classes. The sharp limits in the climate system and the infinite drives of capital accumulation are locked in absolute contradiction. Because members of the dominant classes have a deep libidinal investment in the drives, they will favour a technique for managing the climate that does not require them to be restrained or relinquished. Even the casual American reader of news stories can see the intuitive appeal of this theory. We shall try to add some layers of depth to it below.

What all of this amounted to was a sea change in attitudes. 'Solar geoengineering is becoming a respectable idea,' the *Economist* happily proclaimed in 2023.[82] To mention just one more example, in the following year Pascal Lamy, chair of the Climate Overshoot Commission, came out in favour of the tech in the *Financial Times*.[83] Keith was sullen no more. 'Suddenly we're getting conversations with senior political leaders and senior people in the environmental world who are starting to think about this and engage with it seriously in a way that just wasn't happening five years ago.'[84] There can be little doubt about what caused this change of fortunes: the overshoot conjuncture itself, the transgression of the 1.5°C limit and the structural position of geoengineering in the repository of responses. As these words are written, there is a sense that every month of disaster sees another initiative for bringing geoengineering closer to implementation. But it is not quite written in the stars. In fact, very recently a debacle unfolded for the most high-profiled research project of them all.

In 2018, Harvard University set up a centre for undertaking the first trial in history. It was christened the Stratospheric Controlled Perturbation Experiment, abbreviated SCoPEx, funded by Gates and led by Keith.[85] The plan was to send a balloon and an attached gondola with scientific equipment into the air to discharge select substances and observe how they mixed with others in the air.[86] The site chosen was a space station in northern Sweden, more particularly in the heart of Sápmi, the ancestral lands of the Saami people. They were not asked for their views. They made them known regardless: in early 2021, the president of the Saami Council wrote a vehement protest, citing the 'risks of catastrophic consequences' of geoengineering – including what is known as the termination shock – and

alluding to the colonial nature of the Harvard plan.[87] Leaders of three environmental movements in Sweden also signed the open letter, cc'd to the government of the country, at that point including the Greens.[88] Greta Thunberg, at the height of her fame, rallied behind this opposition. Harvard seems to have been taken aback. The experiment was called off.[89] SCoPEx was down for the count. Keith lost interest and soon left Harvard for another centre at the University of Chicago.[90] In late 2023, the dissolution of SCoPEx was announced: with one single petition, Saami and environmental activists had brought down the most prestigious geoengineering project established thus far.[91] (The final report of SCoPEx ended abruptly with a brief reply to the letter from the Saami Council.)[92] It fell to the clowns of Make Sunsets to conduct the first experiment with balloons and to Stardust to fly the first aeroplane over the slaughterhouse installed for another indigenous population.

The rising tide of geoengineering research and tests thus marked the formation of yet more fronts. Keith, for one, had always been aware of the potential for fightback. In 2001, just before 9/11, he was summoned to the White House. The administration of George Bush Jr had recently taken the US out of the Kyoto Protocol and reaffirmed its denial of the climate problem. But it was quietly looking into other options for dealing with that same problem and invited Keith to address a session on 'Response Options to Rapid or Severe Climate Change', held behind closed doors. 'If they had broadcast that meeting live to people in Europe, there would have been riots,' Keith later recalled.[93] The defeat in Sápmi reinforced the desire for seclusion. 'A lesson I've learned from this is that if we do this again, we won't be open in the same way,' Keith told the *New York Times*.[94] Doing things out in the open might provoke massive riots next time. Better to hide behind the plume of dust rising from Gaza.

By any means imaginary

The Zeitgeist being what it was, injecting sulphate aerosols into the stratosphere was not the sole idea under consideration. 'Geoengineering' referred to an assemblage of technologies for altering the balance of heat between Earth and Sun. One subset aimed higher than the stratosphere: for

space. The earth might be alienated from the sun through some kind of direct intervention in the void between them. In early 2022, an Iranian scientist proposed to hitch the planet to asteroids and harness their force to nudge it out of orbit, away from the sun. He advertised it as ‘an alternative’ to the task of ‘decreasing fossil fuel consumption’.[95] Rather more popular were ideas for placing some object at the Lagrange point between sun and Earth, the location where the gravitational forces from the two bodies cancel each other out, so that things can be suspended in equilibrium.[96] Why not hang a curtain there? It is, after all, what one does in an apartment on a hot summer day.

The imagination knows no limits – particularly, it seems, when it knows no limits to capital. Before Walter Seifritz came up with enhanced weathering, he floated another remedy against the heat: putting mirrors in space. He calculated that blocking 3.5 per cent of the insolation should be sufficient and would require a mere 4.5 million square kilometres of mirrors – an area more than twice that of Saudi Arabia – launched into orbit.[97] A contemporary of his opted for a ‘thin glass shield’ at the Lagrange point, to be ‘built from lunar materials’.[98] Yet another mooted a haze of lunar dust. It would form a reflective film belt around the waist of the earth, making it look a little more like Saturn with its rings.[99] Just as for negative emissions technologies, the late 1980s and early 90s was a moment of brainstorming, when many of the ideas were first thrown out; three decades later, under the pressure of overshoot, they were dusted off and fleshed out with a new urgency.

‘It’s come to this,’ began a piece in the *New York Times*, reporting on stabs at a ‘giant parasol in outer space’.[100] Researchers at Technion – a university forming the hub of the military-scientific complex in the state of Israel – had manufactured a prototype golden canopy it now showed to the world (this was also in February 2024).[101] The finished product would have to be roughly as large as one Saudi Arabia and somehow positioned at the Lagrange point; as a first step, Technion wanted to send a small spacecraft to install its prototype and prove feasibility. One could also think of a sun shield tethered to the earth.[102] Christer Fuglesang, the first Swede to enter space, king of the station where Harvard lost to the Saami, an astronaut-cum-climate-saviour from the Swedish bourgeoisie – ‘Space and climate mastery hand in hand’, ran a slogan of his centre – instead proposed

‘sailcraft’.[103] Vehicles with sails ought to be mass produced and transported to Lagrange. During the launch, 200,000 such vehicles would have to be hurled into space every day. The industry for assembling them would be as large as that for cars.[104]

Another idea was to fill cannons with small ‘flyers’ and shoot them off to Lagrange; essentially a swarm of millions of drones, so thick as to put Earth in a penumbra.[105] A team at MIT intended to construct frozen silicon bubbles and hang them like a slender drapery.[106] Yet another American team looked closer into the option of a dust cloud and examined several candidates: ‘Coal dust is promising.’[107] Not mentioning with a single word the role of coal in causing climate breakdown, or indeed the option of terminating its use, this study mulled extra extraction for putting a cloud of coal dust at Lagrange; in coprological terms, like being all smeared in shit and planning to clean oneself up by shitting a little more and rubbing oneself in just the right spot with it.[108] Sea salt might work too. But the team eventually settled on the old idea of lunar dust: blast the surface of the moon into fine grains and then use some ballistic device – a railgun perhaps – to shoot them into place. The mass required would be 700 times heavier than everything that humanity had launched into space since the early 2020s.[109] This seemed doable to the inventors. And we have now observed this pattern so many times as to be able to safely conclude that, beyond the concrete details of each concrete technology, we are dealing with a systemic pathology of which these technofantasies were the symptoms insofar as they set out to combat symptoms. Because it was unimaginable to attack fossil capital by any means necessary, it was necessary to protect it and the planet it ruled by any means imaginary.

All of these schemes for space-based geoengineering shared comparative disadvantages: they relied on futuristic technologies, decades away from maturation. They would take a very long time indeed to put in place. Costs might be prohibitive.[110] In a control emergency, the demand would be for something different: a technology within easy reach, ready to be launched, without having to wreck the world economy – more like a Covid vaccine or an Iron Dome, less like terraforming Mars. Stratospheric aerosol injection remained supremely attractive in these respects. What Make Sunsets, SATAN and Stardust all did was something that actually could be done. The stratosphere, not space, looks set to be if not the final then the main frontier

for the foreseeable future. We shall focus on this category in what follows; unless otherwise stated, ‘geoengineering’ will refer to it.

Bill Gates does not yet own the world

But first we must mention a subset of planetary engineers that looked down rather than up: to an enhancement of Earth’s albedo. If the Sahara and the Arabian and the Namib deserts were all wrapped in bright plastic sheeting, the warming in the pipeline could be postponed for nearly a century. Maintenance could be delegated to robotic vacuum cleaners and monitoring to satellites. (From the appendix of caveats: ‘The cover will kill all plant and animal species in the covered areas.’ Furthermore, ‘some of the countries of the target areas are politically unstable or may not be agreeable to this use of their land’ – for example, Niger losing virtually all its territory. ‘However, many of these countries are also impoverished and debt ridden and if debt forgiveness was substituted for payments they would receive for use of their land, many would probably agree to participate.’[111] The fact that white people can come up with such ideas.)

Painting rooftops white could help alleviate heat stress in cities.[112] Brightening crops might give relief to areas plagued by heatwaves; their genes could be modified to make them reflect more radiation.[113] Here geoengineering shades back into muscular adaptationism (and, potentially, into removal: plants could be manipulated to both capture more CO_2 and absorb less heat). Without the destruction of business-as-usual, such measures would run into the familiar problems, as continued emissions would eventually ‘dwarf any regional cooling’.[114] These would be localised palliatives. They would not aim at the total symptom of average global temperatures but at cooler shades over this or that region. Geoengineering would here be an adaptive project targeting a town or a breadbasket or a surgical operation to stave off a tipping point in one subsystem.

Special designer umbrellas could be folded over the Arctic to bring it back from the brink.[115] One could coat its ice in a blanket of glass microspheres to make it throw off heat and break the albedo feedback (authors reported no adverse effects on some fish and bird species but deferred detailed research on the fates of ecosystems to be thus covered in

glass).[116] The Centre for Climate Repair at the University of Cambridge looked to rescue the Arctic ice by other means: brightening the clouds above it. If the droplets that make up a cloud form around a few large nuclei, they will be relatively dark. If they rather condense around many miniscule particles, their albedo will rise and more insolation bounce back after hitting the clouds.[117] Ergo, smash salt crystals and shoot them into the atmosphere, shatter the darkness and save the Arctic under a bank of wispy clouds. The Centre for Climate Repair aspired to have 1,000 ships equipped with cannon-like nozzles crisscrossing the Arctic Ocean within a decade.[118] (This was the idea Soros took to heart.)[119]

This latter thing was 'marine cloud brightening' – a technology in which the world already inadvertently dabbled, as exhaust from ships generates tracks of white clouds over their lanes.[120] The particles for a brightening operation may consist of ordinary soot or dust or even bacteria.[121] But salt from seawater would be the most natural solution: haul it up on deck, drive the salt crystals through the nozzles and spray them into the air, where they will dry in tiny specks for drops to latch onto. Extreme uncertainties surround the idea. When the Great Barrier Reef suffered near-death experiences from bleaching in the late 2010s, a group of Australian researchers brought out the cannons and set them roaring over the corals to examine whether they might give some comfort, however brief.[122] It would be an antipyretic pill aimed at an extremity particularly close to overheating.

Marine cloud brightening could also be deployed to enhance the albedo of the earth as a whole; to study the potentials, the US government in 2022 recommended field experiments.[123] Two years later, a decommissioned aircraft carrier quietly got to work in the San Francisco Bay. It was outfitted with cannons for firing not projectiles but liquified salt. The researchers were apparently so nervous about a backlash that they refrained from informing the public and kept the cannons going for a mere twenty minutes.[124] When the story broke in the *New York Times*, the city council of Alameda, in whose waters the ship operated – the members shocked to learn about it from the news – ordered the researchers to immediately quit and get out.[125] The council was not thrilled about a cloud of chemical compounds in the Bay, nor about the furtiveness of the exercise. This was the ignominious end for the first American experiment in marine cloud

brightening.[126] (One and a half decades after Gates threw hundreds of thousands of dollars into another that he hoped would be the first.)[127]

Once again, some contradictions of geoengineering were thereby brought out. If experiments are undertaken outdoors, among people with basic rights and an awareness of what's going on, chances are that they will be thwarted. The legal vacuum of the Silicon Valley culture industry or the Zionist occupation of Palestine proved more congenial to tests. While it might be true that 'geoengineering cannot at this point be wished away', it was evidently possible to throw spanners into its progress: the Mexican government expelling Make Sunsets, the Saami blocking Harvard, the Alameda council fencing off the Bay – here was a triad of setbacks.[128] And the battle had barely begun. There had, as yet, been no riots. But everything indicated that this front would heat up quickly, and that, although other technologies might enter the fray, stratospheric aerosol injection would stand at the centre. What could it do to this world?

15

Permanent ~~Revolution~~ Eruption

The basic physics are well understood. Aerosols suspended in the sky stand in the way of rays from the sun. They scatter the incoming sunlight, down, to the sides and back into space. It happens all the time; the air naturally contains aerosols – dust, organic matter – and economic activity by humans supplement them with effluents, such as soot.[1] It follows that if more particles of this kind are lofted from the ground and into the atmosphere, more solar insolation will indeed be intercepted. Temperatures on Earth will fall. In fact, this had happened before. It was the 'kill mechanism' for the fifth mass extinction, the K-T-event that wiped out the dinosaurs: an asteroid ten kilometres in diameter smashed into the Yucatan peninsula with such force that the crust of the earth vaporised at the site of impact and a cloud of dust, ash, sulphur and other aerosols rose into the atmosphere, encompassed the globe, shut out sunlight and sent temperatures plunging. The ensuing 'impact winter' eradicated the habitats where dinosaurs could live.[2]

In the more recent past, the notion of a 'nuclear winter' hinged on similar causes and effects: atomic bombs set a giant match to cities and industrial areas and entire landscapes, black sooty smoke shoots into the air, particulate matter lingers in the stratosphere, temperatures plummet, the dark and the cold kill crops, food supplies for humanity collapse. The use of a fraction of the world's still existing nuclear arsenal would be enough to inaugurate such a season.[3] In other words, a nuclear war caused by inter-imperialist rivalry or some other geopolitical antagonism – between the US and China, or India and Pakistan, or Israel and Iran – would go some way to suspending the results of fossil capital. Ironically, the lead author of the first

scientific paper warning about the climatic implications of atomic warfare in 1980 was Paul Crutzen, the man who later jolted the research community by speaking for geoengineering.[4] Not inaptly, an early paper referred to this technology as 'a controlled "nuclear winter"'.[5] It would be a nuclear winter summoned and appreciated for its own sake: not the Armageddon of an atomic bomb, but a *controlled* change of seasons.

The favoured analogue, however, has always been volcanoes. A large enough eruption will spew out sulphur into the stratosphere – picture a billowing pyroclastic cloud – where it might stay for a year or so. The most recent incident of size is still, as of this writing, the outbreak of Mt. Pinatubo in the Philippines in 1991: an immense volume of lava and ash, the largest ever recorded by modern instruments, hoisting up some 20 million tonnes of sulphur.[6] A haze enshrouded the globe. Average temperatures fell by half of a degree for at least one year afterwards. Serendipitously, this happened just as brainstorming was underway, and so geoengineering came to be colloquially known as 'the Pinatubo option'. Volcanoes get close to live demonstrations of what can be achieved with a mountain of sulphur; on this observational basis, the effect is virtually guaranteed. The science leaves little doubt that injection of sulphates into the stratosphere would accomplish a temperature drop. Taking out 1 or 2 per cent of sunlight might be enough to undo the effects of the past two centuries of large-scale fossil fuel combustion; as long as such combustion continues, the hit rate would have to increase, but the accuracy would still be there for the taking.[7] But the analogy is imperfect. Aerosols from volcanoes drizzle back to Earth within months by the workings of gravity. Eruptions come in single pulses. For geoengineering to work, the sulphur would have to be replenished through continuous injections, or else the effect would slip away like water between fingers – there would have to be a permanent eruption, a Pinatubo that does not rest and never goes out.[8]

Once global warming had crossed 1°C, to volcanoes were added another natural – or not so natural – analogue: wildfires. The conflagrations that ripped through the forests of Canada and Australia from the end of the 2010s onwards were mini-Pinatubos in their own right, sending enough smoke into the stratosphere to offer fresh insights into both nuclear winter and geoengineering.[9] The modified bomber taking off from Houston waited for the next mega-wildfire to provide sulphate to study.[10] These, then, were

the auspicious analogues for the technology, in chronological order of appearance: the asteroid that extinguished the dinosaurs, air pollution, the atomic bomb, the eruption of Mt. Pinatubo (and other volcanoes), wildfires above 1°C. All suggested that humanity could cool the earth by imitating such violence and lifting sulphate in a controlled, deliberate, artificial, sustained manner. By what kind of device?

Pick your gun

The party balloons of Make Sunsets would probably not be up to par. The fighter jets of Israel would be more like it. Aircraft have long been seen as the most suitable deliverers. To tuck sulphate into the stratosphere and have it stay there for as long as possible – preferably a year – it needs to be transported some twenty kilometres above Earth; lower down, it will drop to the surface within weeks. Existing business jets cannot fly that high, but spy planes and other military jets routinely do so. They could be tweaked for the job. One leading thinker on the topic, Wake Smith, came from a career as a CEO of sundry aviation companies and president of the training division of Boeing. To see what could be done, he called up his pals in the latter corporation (and others in the business, of which more below). The team came up with a customised design for high-flying sulphate planes. It would have abnormally long and large wings so it could cruise in thin air. The fuselage would be narrow, filled not with passengers who need space but with chemicals: a payload of molten sulphate, combusted onboard and released into the winds. These would be specialised single-purpose machines, like ‘water bombers that are used to fight forest fires’.[11] They would scream up to their intended altitudes above the tropics within ten minutes, and from there the sulphate particles would slowly make their way towards the poles; then they would return to base and go up again, with the next load, and so on, and so on. The permanent Pinatubo would rise on wings.

The challenge of building a workable fleet of this kind could be met by private industry within ‘several years’.[12] A military crash programme could churn it out faster. This would not be cost-free. The design effort would command resources, although not too many. No major technological

breakthroughs would be called for; the injection vehicles would synthesise existing features of planes. Airliners and air forces could afford the mission.[13] It would be rather the cakewalk for the armouries shared by the US and Israel. What other costs might there be? The sulphate itself is currently ‘dirt cheap’ – geoengineering would augment demand but not render the material scarce; from Vesuvius to India, volcanoes and limestone hold it in abundance.[14] Instead, fuel is thought to be the main cost factor (or, if one prefers, circulating capital). It would, of course, be fossil. The price of jet fuel and thereby the geoengineering fleet might, somewhat perversely, soar if mitigation were to occur – say, carbon rationed or rigorously taxed. And then there is the labour, which, in the form of aircrews, would have a fantastically strong bargaining position: strikes could put civilisation itself in peril, as more aerosols would trickle down without being replenished for every week or month of work lost. One could imagine a kind of class struggle that would turn the geoengineering pilots into the cream of a labour aristocracy – or perhaps more likely, induce a round of automation that would issue in unmanned, remote-controlled, drone-like planes (which, however, would still necessitate service crews on the ground). Or the personnel might develop a loyalty to the powers that be and an *esprit de corps* as the stratospheric police force. Technological development might reduce costs further.[15]

It would surely be an industrial undertaking of massive proportions: many millions of tonnes of sulphate extracted from underground deposits and ferried to hundreds of planes taking off from a network of bases, all integrated in extensive supply chains and surveillance systems. Even so, the consensus holds that total cost for the technical apparatus would easily be within the means of an advanced capitalist country. Smith derived a ballpark figure of $30 billion for the global geoengineering operation in the year 2100 and pointed out that it equals the sum spent early in the century on pet food in the US. If that sounds paltry, it would also – a mathematical equality perhaps denoting a certain irrationality – consume every military budget of the world, save for the ten largest. It would even exhaust the fortunes of individual billionaires (at their levels of net worth around the year 2020). No Gates or Musk could do it alone (as of now); at least one ‘major economy’ would have to be involved.[16] At a fraction of the stimulus programmes rolled out after the crash of 2008, however, the price tag for geoengineering is unlikely to be a decisive factor in a decision to deploy.

Measured in cost per degree of suppressed temperature, the economics of geoengineering do indeed appear 'incredible'.[17]

Other delivery systems have been put forward. In *Termination Shock*, the sulphur is sent skywards in large shells fired off by massive cannons buried deep in the ground.[18] Balloons have had their proponents; these could float freely, as per Make Sunsets and SATAN, or be tethered to the earth. Some have envisioned the construction of the world's tallest tower with an inbuilt hose to pump the sulphate or an elevator taking the stuff to a satellite. All of these alternatives have drawbacks. Cannons do not distribute soot as evenly as planes; balloons are unreliable; towers of the required length would hardly withstand the ferocious winds of the jet stream.[19] But future marvels can, of course, not be ruled out. In the same vein, other aerosols than sulphates have been put on the table: salts, alumina, calcite, diamonds, the latter two solid minerals that would be ground to powder and set aloft.[20] Within every technology, a kaleidoscope of fantasies. Imagine underground cannons firing pulverised diamonds into the sky to defuse the effluvium from capital accumulation that was never brought under control.

Guaranteed effect

The most certain outcome would be global re-cooling – or, depending on the level of ambition, decelerated or annulled warming. The sulphate screen would slow down the rise in temperatures. Make it thicker and the rise could be fully stamped out; thicker still and it could be turned into its opposite, such as a cooling by 5°C.[21] Beyond this certitude, not much is known. Experiments of the kind undertaken in the early 2020s may allow researchers to study how sulphates move in the stratosphere, like flinging snowflakes in the air and watching them fall.[22] But they cannot shed light on how the climate system would react to a permanent eruption. If one had access to several Earths, one could engineer the atmospheres on some of them and not others and compare the results. Unfortunately, the universe does not allow for such testing, which means that any advance knowledge about the mechanisms of geoengineering will be theoretical. The only empirical field trial would be full implementation. Scientists are therefore left with climate models in computers and other roundabout exercises for

approximating at least the rough contours.[23] And the body of research thereby generated, as of the early 2020s, did suggest that dampening the global fever would also – by rather plain logic – take the sting out of the worst symptoms.[24]

There would, for example, be fewer heatwaves. People would not have to go through as many and severe and deadly hot spells as under untreated business-as-usual.[25] With less heat entering the oceans, hurricanes would be less frequent and powerful.[26] Avalanches in the tipping elements might be arrested. Model simulations predict that geoengineering would save the Greenland ice sheet – or at least parts of it, contingent on myriad factors.[27] Much of the West Antarctic ice sheet could be caught floating in the air, before it hits the oceanic basin of attraction; but only if emissions go down and injections begin right away and the earth is cooled down to 0.5°C above preindustrial times, a finding consonant with the possibility that this nodal line has already been crossed.[28] Sea level rise would tail off.[29] AMOC might be kept in some degree of motion, Arctic Sea ice rebooted, permafrost salvaged, total area of wildfire held to a minimum – all depending on the size and timing of the doses and the heating they must overcome and slews of other variables; but the general promise emerging from the modelling is of a tipping halted.[30] By the same token, feedback mechanisms in the carbon cycle would calm down.[31]

We can then readily imagine just how irresistible a temptation geoengineering might become in the near future. Virtually overnight, it would work wonders for the heat. The best crystal balls indicate that it would interrupt the major avalanches – not with certainty, but with some likelihood, and nothing else has that potential. But insofar as the dialectics of disaster works in favour of geoengineering, this technology also has its potentially very negative side effects. And they are legion.

The end of climate

On the way out from Earth, infrared radiation bumps into the greenhouse gases. We might think of them as an invisible halo, sitting everywhere at the same distance from the globe, warming the troposphere below, day and

night. Their effect is even. The atmospheric concentration of CO_2 will be roughly as high over Antarctica as over Ankara. Incoming sunlight is another matter: it strikes the surface as shortwave radiation – and not at all uniformly. More of it reaches the equator than the poles, more arrives in summer than in winter; it obviously does not materialise at night. If a sheet of substances is wrapped around the globe to obstruct this incoming sunlight, the effects will be uneven in space and time: during polar winter, for instance, close to none. No sun would have struck the Arctic in mid-January anyway. It would be like a solar eclipse in the darkest hour. But a stratospheric layer of sulphate will make an appreciable difference at noon in the sun-bathed tropics. For this reason, all modelling demonstrates that average cooling would translate into comparative 'overcooling' of the tropics and 'undercooling' of the poles; in other words, the former would get a lot cooler, the latter just a little.[32] Now it so happens that the steep temperature gradient between equator and poles drives much of the weather systems on Earth, those awesome conveyors of warm and cold air that regulate the routes of trade winds and jet streams, the location of rain belts and deserts, the alternation between wet seasons and dry – what is locally experienced as rain, storm, calm, thunder. How would they fare if the gradient tends to flatten out?

An analogous levelling effect applies to seasons. Because there is more sunlight to reflect in summer than in winter, the sunshade would be more consequential for the former: overcooling summers and undercooling winters, the more so the higher the latitude. The amplitude of the seasons in Scandinavia could diminish sharply. Summer – as registered in temperatures, snow cover, extent of sea ice – would appear less different from winter and vice versa.[33] An additional mechanism of this seasonal equalisation is the paradoxical fact that extra amounts of sulphate aerosols would cool the surface of the earth, but warm the stratosphere: like soot flakes hanging high, they would absorb radiation and turn up the heat of the air some twenty kilometres above. Such upper heating could react on the weather below and push air currents off their tracks and blur the seasons even further.[34]

But to add to the complications, flattening is, of course, already an element of global warming. Polar regions heat up much faster than the tropics, closing the latitudinal gap. Geoengineering would counter this trend with its opposite: the tropics would cool down faster and encroach on the

poles, as it were. Which one is worse? The upshot depends on how much the gap has been closed by warming once geoengineering is launched, how aggressive the injections are, how much the preceding trend is pushed back, how the baselines shift over the decades from extreme warming to more or less extreme cooling: chances are that abrupt changes will set off a seesaw of levelling. But some modelling suggests that the albedo feedback at the poles will be too strong for geoengineering to bring it to an end; by the time the planes are in the sky, residual Arctic (and Antarctic) warming will be self-acting and unstoppable.[35] In that case, a geoengineered world would affect its own levelling (overcooling the tropics) on top of the inherited trend (overwarming the poles) – the worst of two possible worlds, less a seesaw than a squeeze. The tropics and the poles would move closer from both directions. Seasons in the north would narrow correspondingly.

Diurnal cycles would go the same way: less contrast, though here the effect might be marginal.[36] Land would cool faster than the heat-storing seas. Because there is more land in the northern hemisphere than in the southern, it would depart on its own path of cooling, and this would be merely a beginning.[37] The climate system as we know it could come apart at the seams. *Ex ante* knowledge of geoengineering points to its capacity to scramble regional climates and send them off like rafts on a swirl of eddies, their courses and ultimate destinations impossible to foretell. It follows that heating the earth beyond the identified temperature limits and then cooling it down by aerosol injections are two disparate processes, whose fingerprints on the climate do not match – very unlike a thermostat turned up and down in a four-wall room.[38] This would be no more of a time machine than removal would be. It would drive the planet into a future where the climate system as we know it might come to an end.

Let’s give the Earth to Donald Rumsfeld

Rainfall is a matter of some importance, and perhaps the most precarious parameter in modelled geoengineering. When the world warms up, the hydrological cycle – the perpetual circulation of water, from rain or hail or snow to runoff and evaporation and back to the clouds – intensifies. The more energy that accumulates in the system, the more water evaporates due

to the heat, the more water vapor fills the warmer air: hence the torrential rains and flash floods. Geoengineering would invert the trend.[39] With some of the sun blocked out, the cycle would lose energy input. It would slacken, meaning a decline in overall precipitation. Drops of this kind are found not only in the models, but in the record of weather observations: volcanic eruptions regularly bring in their wake lower levels of rainfall, less water discharged from rivers, looming aridity in regions sensitive to variation. How would a permanent Pinatubo play out? If it is turned up to a degree where it compensates for all warming, it would, simulations suggest, stifle the hydrological cycle more than it had previously been amplified – that is, the countereffect would be larger, bringing the Earth back not to the pre-industrial point of departure but to some unfamiliar state of flickering rain.[40]

The advantage would be fewer deluges. Atmospheric rivers would be blocked from drenching East Asia in water.[41] Sub-Saharan Africa would be spared the most destructive downpours.[42] Under climate change, already wet regions tend to get wetter and dry drier; in a geoengineered world, the wet would get drier and the dry wetter – a taking of water from the rich and giving to the poor, if you will. But this would not be a redistribution without risks. The average effect would be less rain: in the informed assessment of Keith himself, geoengineering would ‘exacerbate water stress’.[43] The effect is likely to be strongest in the tropics.[44] For the past 5,000 years, a belt of clouds known as the Intertropical Convergence Zone has hovered around the equator, encircling the globe where trade winds from north and south meet, keeping the land underneath muggy, regularly pouring out torrents. This zone is magnetically pulled towards heat. If geoengineering does cool the northern hemisphere more than the southern, it would migrate southwards; if this cooling is more pronounced in summertime, the push would be seasonally boosted. The result could be a devastating absence of rain in the Sahel.[45]

Geoengineering might cause a desiccation of tropical Africa; but perhaps even more vulnerable is India.[46] Delivering eight tenths of the precipitation over the subcontinent, the Indian monsoon is a bedrock for more than one billion people. Here is an empirical law from the past three centuries: every major volcanic eruption has caused a failed or feeble monsoon due to reduced polarities in temperature between the hemispheres and a dislocation

of the Intertropical Convergence Zone. And here is a uniformly recurring result of the model simulations: keeping the artificial eruption going would cement the pattern. It would deprive India of so much of the monsoon as to induce a chronic drought.[47] A similar fate might befall the tropical lands to the east, from Myanmar to Vietnam.[48]

Filtered through the smog, the sunlight falling on planet Earth would be more diffuse. This could be good for some plants. Direct light hits the canopy, but diffuse radiation penetrates it and spreads like a glowing blanket over the shaded leaves. An opaque stratosphere would stimulate photosynthesis in the understory, and cooling, by definition, lessens heat stress: crops might fare better.[49] But not all thrive in the shade. For many edible plants – maize, rice, soy, wheat; staples all – the hazy light would be detrimental and any yield gains from cooling nullified.[50] Solar panels would be starved of fuel. It is a tautology that a reduction of insolation amounts to global sabotage of solar power. Photovoltaic and centralised systems alike would have less sunlight to run on, suffer more weeks of insufficient supply, require greater land area to function, cost more – as if geoengineering were thought up to reverse not climate change but the secular gains of solar power and its conclusive victory over fossil fuels as a source of electricity.[51] Winds would subside. Sulphates in the stratosphere would send the circulation of air hither and yon. Weeks of calm would become more common around the world, with the shortfall predicted to be worst in China, the American West and much of the southern hemisphere.[52] Surely this would be among the most perverse, not to say reactionary side effects. It would amount to a revenge for the stock against the flow, a physical debilitation of the alternatives to fossil fuel – making mitigation more burdensome, increasing the need for geoengineering, hampering solar and wind even further, and so on.[53]

The blue sky would take on a milky white hue. In cities already enveloped in smog, the difference might be hardly perceptible; but the sky in rural areas would have a novel pallor.[54] This particular side effect became something of a poster child for geoengineering with *Under a White Sky: The Nature of the Future*, Elizabeth Kolbert's best-seller on the topic.[55] And to the human eye, this might indeed be the most striking and disturbing change: the heavens blue since time immemorial, blue no more. On the upside – possibly – sunsets would become more spectacular, flashing up in

the warm crimson colours familiar to inhabitants of Tehran or Beijing.[56] This was the charm of the company name Make Sunsets. But anyone in the business of making sunsets would in the same stroke also hide the stars from view. The telescopes astronomers use to train their eyes on distant celestial bodies would face an obstacle.[57] Of less romantic concern is the eventual return of sulphates to Earth, where they would pollute the air: there would be more fine particulate matter in people's lungs and more acid rain, differences again most noticeable in pristine areas.[58]

Ozone depletion would speed up. It has done so after volcanic eruptions, because sulphate aerosols per se and stratospheric heating both accelerate the cycle destroying that molecule. The recovery of the Antarctic ozone hole could be delayed or foreclosed, geoengineering thereby negating one of the few triumphs of environmental protection – the Montreal Protocol – under late capitalism.[59] This has been the main motivation for scientists to explore alternative aerosols, such as calcites or diamond powder. But these could come with adverse reactions even harder to predict, as they don't exist naturally in the atmosphere (not to mention that diamonds would drive the costs up to preposterous heights).[60] If the stratosphere fills up with good old sulphates, the chemistry of the troposphere will be remixed, SO_2 dripping in from the attic; what might happen to the compounds in this ground layer is an open question.[61] The aerosol clouds could corrode the wings of the planes themselves.[62] To have them fly in flocks, infrastructure would need to be extended: apparently there would need to be a massive airport complex constructed in Tierra del Fuego, the tip of Patagonia, to deliver loads over the south pole.[63] All the tarmac, the hangars, the houses for crews, not to mention the mining and transporting of sulphur would involve a cluster of consequences of their own.

To this should be added the limitations of geoengineering, all that it cannot achieve. If CO_2 concentrations keep rising, it does not matter how much they are counterbalanced by aerosols: the oceans will continue to acidify. The seawater will go on swallowing a rising surplus of CO_2, possibly even at a higher rate, since lower sea temperatures, as we have seen, increase the solubility of the gas.[64] Nor can the protracted heating of the oceans be overturned posthaste.[65] Undercooling of the poles would mean a hard struggle to curb the warming of the Arctic, further complicated

by the reaction of plants in the north to an atmosphere filled with both CO_2 and SO_2.[66] The ice might thus continue to melt and the permafrost to thaw; as less rain and snow fall over boreal regions, wildfires could resume.[67] We know from the science of tipping points that reversibility is not in their constitution. Geoengineering could prevent or slow down their arrival or modulate the speed of collapses; but it cannot with facility erect dominoes already toppled.[68] There are, strictly speaking, no guarantees that sulphate planes would be any more effective in rolling back avalanches than DAC plants or fossil fuel bans. Not every control emergency produces a measure on a par with the challenge. If it is constituted by feedback mechanisms already deep down their sliding motion, geoengineering could be nearly as powerless as removal or mitigation: at some point, it would be too late even for the mightiest sulphate eruption.

As for actual effects, uncertainty appears – beyond the average cooling – to be rule rather than exception. The earth is so coupled and complex, so overdetermined a totality as to defy any predictions about how geoengineering would unfold downstream of the injections. The potentials for splintering effects and ricochets and reactions in the second and third and fourth instance à la Engels are plainly incalculable, even more than for negative emissions technologies. This is due not to impaired science, but to the nature of the system in question. From the largest planetary mechanisms down to the tissue of leaves, geoengineering would have repercussions that could ripple across scales and instigate all manner of non-linear processes, episodes of self-organised criticality proliferating in the most unexpected directions.[69] The chance that the last side effect will have been discovered in advance is nil. Here the appendix stretches into infinity.

One prominent expert in 2022 admitted to total ignorance: ‘It’s difficult for me to say whether I’m for or against stratospheric aerosol injection because it’s hard for me to even understand what I’m giving an opinion on.’[70] Science adopted the phrase ‘unknown unknowns’ from Donald Rumsfeld, who used it to denote the surprises that could not be anticipated or even imagined in the country of Iraq; applied to the planet as a whole, geoengineering would be a leap into epistemological darkness.[71] But this would be a recognisable turn of events. With metabolic rift theory, we could say that geoengineering would cover up the original rift and shift it elsewhere, into derivative ruptures opening up one after the other – and

with David Harvey, that capital ‘never solves its crisis tendences: it merely moves them around’.[72] Or, the shit is diverted, the hoses turned blindly and randomly in other directions. Sulphate aerosols are, of course, a component of the shitstorm of fossil fuel combustion: here they would be isolated and produced as shit to cover up shit. This is the future towards which the world edged in the early 2020s. Outdoor experiments – and we can now recognise Stardust as the step it was for humanity: the first sulphate planes in the sky – might demonstrate the viability of the technology. But they can never reveal the secrets of the side effects lying in wait.[73]

The law of the tendency of side effects to rise

Amid this clutter of uncertainties, however, one certainty can be laid down as a virtual iron law, and it is of the greatest moment. *Every negative side effect from geoengineering will worsen the longer it goes on and the larger the quantities of sulphates injected*. In the beginning, these may not cause much trouble. Insofar as there are positive effects, they will come early on. After the first year of flying rounds, the accomplishments are likely to overshadow any byproducts on the horizon: but if the mission goes on, the side effects will start to kick in. The flattening of latitudinal gradients, the levelling of seasons, precipitation collapse, monsoon failure, withered crops, starved solar plants and wind turbines, whitened skies, air pollution, ozone depletion – all are hardwired to escalate with the duration of the operation and, no less importantly, its magnitude. If CO_2 continues to build up in the atmosphere and the injections come in larger doses, the side effects will grow commensurately (or grow even more). None might be detectable in the first instance.

To this law is appended a problem of coagulation: unlike a one-off volcano eruption, continuous addition of sulphate aerosols into the stratosphere makes them attach to one another and form blobs. By the laws of gravitation, they will then fall faster to the earth, so that more aerosols will have to be injected to maintain the cooling effect, further promoting coagulation, and so on.[74] Then in 2024, modellers happened upon another set of effects in their idealised simulations: the longer sulphate injections go on, the more they will reduce the albedo of clouds, through mechanisms

barely comprehensible to anyone outside the circle of specialised atmospheric chemists – if even to them – sapping the power of geoengineering and demanding larger doses, like an addict who can no longer get high from just one shot.[75] All of this would add to the financial burden. A growing operation – a second generation of planes, more bases, spare parts, back-up systems, security, a larger quantity of aerosols – would incur greater costs, as would, if taken into account, any mounting side effects.[76] It cannot then be excluded that the price for geoengineering eventually does become a drag. This too has a strict temporal logic. Call it *the law of the tendency of side effects from geoengineering to rise*. No countervailing factors so far uncovered, the science points to it as an absolute law. It is of central importance for any speculation about how this process might develop over time and whether a terminal breakdown is to be expected.

Return of the repressed fire

Of all the risks with geoengineering, none approaches the enormity of its sudden termination.[77] Imagine it is the year 2130 and the operation has been going on for a century. Heat latently stored in the atmosphere has been masked by flights continuously shooting out soot. But then something or other happens and geoengineering is abruptly terminated. The mask is ripped off, all the pent-up heat set free to do its work. The effect would be similar to that of standing with one's face pressed to the glass door of an oven, inside which a fire is roaring and raging: and suddenly the glass shatters and the flames leap out. This is the termination shock, a risk inherent in the constitution of the technology. Because aerosols naturally drift back to Earth, and insofar as their function is to undo the damage of the emissions, any interruption to the injections would set it off.[78] There would be a pulse of warming as the repressed heat returns in full force.

How much heat exactly? This depends, of course, on what has happened to the atmospheric carbon content in the meantime. If, come 2130, emissions have been reduced to zero *and* removal has drained the atmosphere of the historical accumulation and returned the concentration to, say, 350 ppm, termination would not cause a roasting of the planet. It would

be rather like pulling off the plaster from a healed wound. Insurance against the termination shock, in other words, presupposes that *mitigation and removal both succeed in slaking the latent fire in lockstep with the injections*. But this is not an innocent premise. Negative emissions technology might not, as we know well by now, have the desired potency. It cannot be safely assumed they will empty the atmosphere of excess carbon during the century (or more, or less) of geoengineering. More concerning still, mitigation might remain as retarded as ever.

Imagine that, between initiation and termination, fossil fuel combustion continues, if only at a lower rate. Suppose, for example – a mid-range scenario, far from the worst – that annual net CO_2 emissions between 2030 and 2130 average half the level from the first year.[79] A whole lot of additional carbon will then be deposited in the atmosphere, ready to drive up temperatures – if it were not for the canvas of sulphate aerosols, thickening *pari passu* so as to hold off the radiative forcing. The latent heat at the moment of termination would then be considerably larger than what was initially repressed. If CO_2 concentration doubles or quadruples over the century, so much more would rush forth: and the result could be exceedingly cataclysmic. The higher the concentrations the operation has cancelled out, the more aerosols it has kept afloat, the greater the severity of the snapback.[80] A corollary follows. *If geoengineering creates an incentive to let fossil capital live on, the risk of a severe termination shock rises*.[81]

How bad could it be? It will not be gradual or smooth, as in Robinson's storytelling. If injection is called off from one year to the next, the ensuing spike in temperatures is likely to be utterly non-linear. The heating would be several times faster than any pre-sulphatic business-as-usual could achieve on its own. For obvious reasons, simulations have thrown up a range of estimates: a heating twice as rapid as the maximum rate under hitherto experienced business-as-usual or five or sixteen or twenty times greater than early twenty-first-century warming.[82] We are here talking about average temperature on Earth jumping by perhaps half a degree per year or four or five degrees per decade – whatever the exact figure, a heating so precipitous that it would have 'no precedent in the geological history of climate'.[83] Only the impact winter of the dinosaurs would provide a meaningful parallel. Any accomplishments from the century of geoengineering would be turned inside out: an AMOC kept in circulation

would fall into paralysis.[84] Carbon stored in sinks would be exhaled in concentrated fumes.[85] Precipitation would rebound and the hydrological cycle go into overdrive over the course of a few years – a condensed chaos crashing through the planet best left to the imagination.[86]

To a punctuation of such proportions, no ecosystems and precious few species could adapt. Birds, fish, reptiles, mammals – none would have experienced climate dislocation at anything near post-termination velocity; minorities among them would avoid extinction.[87] Humans would only be marginally better off. Planting crops when temperatures shoot up from one season to the next is a well-nigh pointless endeavour. In a world of three, four, five degrees of warming per decade, food supplies would dwindle.[88] Alongside nuclear winter and hothouse Earth, this is the most apocalyptic scenario known to climate science.[89]

A best-case combination of mitigation and removal would protect against it: but not entirely. Even if the CO_2 concentration is back to 350 ppm in 2130, a stop would throw the planet out of its ruts. During the preceding century, regional climates would have settled into some kind of novel state under regimes of precipitation, evaporation, radiation and loads of other factors determined by the injections. Upon their cessation, the jerk would be violent, even in the absence of heat flashing up: there would be a reshuffling of climes (the general case for any overshoot-and-return, as we have seen). Societies that would presumably have adapted to the geoengineered century and learned to know it as the new normal would face the unknown realities of a post-geoengineered future – less bad than being grilled, surely, but still pretty bad. We may thus introduce a distinction between two types of termination shock: roasting and reshuffling. We shall focus on the former, since it is functionally related to the dynamics of prolonged and potentially indefinite overshoot – a not implausible scenario, as we know well. The most overwhelming danger any geoengineering scheme would have to grapple with is *unterminated emissions during the period of deployment*.

A small foretaste of the shock might have been registered in the early 2020s. Humans have released aerosols into the atmosphere for centuries, by burning first wood and then fossil fuels, the warming jostling with a cooling from the same sources. Two steps upwards on the curve have been matched by one step back. By the early 2020s, greenhouse gases had caused a

warming of 1.5°C and aerosols a cooling of 0.4°C – meaning that average temperature would already have risen by 1.5°C without the air pollution, although estimates of this effect vary significantly.[90] Controversies pertain to the magnitude but not existence of the counter-influence. Now because air pollution was the second largest cause of human death on the planet, eclipsed only by heart disease, killing far more people – 7 million every year – than military conflicts, some ambitions to clean the air of soot were occasionally mustered.[91] In 2020, governments agreed to lower the allowed sulphur content in shipping fuels. The most heavily polluting variants were essentially banned. In one fell swoop, global ship tracks were reduced by 50 per cent – not a termination but a halving, attesting to what regulations can achieve.[92] From a climate perspective, this was akin to ordering the manufacturers of poison to remove the elements diluting it. The sulphur layer blocking incoming sunlight shrank and clouds over ship lanes darkened.[93] Then in the beginning of the decade, a spurt in warming followed, with 2023 seeing the fastest rise in temperatures until that date: and some modelling generated a perfect match to the unmasking over the seas. On this hypothesis, the spurt was largely a result of a proto-termination shock.[94] It remained controversial, as so much else in this subfield; but the incident did not augur well.[95] The rational thing for governments to do would, of course, have been to cut the sulphur *and the fossil fuels in which it was mixed*.[96] But that would have meant cutting into fossil capital and the gold gained from the poison; merely imposing some fuel standards was a path of less resistance. What precedent did this set for a geoengineered future? It does not seem like a lesson in the rationality of the world or, more particularly, in the readiness of governments to cut back on fossil fuels before taking off their mask.

Insofar as the world – China included – made some efforts to clear up the air in the early twenty-first century, geoengineering would have the opposite profile: injecting massive amounts of sulphur into the air. Any termination would then unfold differently. Two categories of causes have been broadly identified. The trigger could be exogenous, a factor outside the workings of the system itself. Terrorists could shoot down the planes. A war, a pandemic, a total crash of the world-economy, a series of unheard-of natural disasters – earthquakes, asteroids – a wave of revolutions, perhaps even (although it would seem a self-destructive form of proletarian action) a

general strike that sweeps up the pilots, could knock out the just-in-time infrastructure for keeping catastrophe at bay. One team of scientists has considered a scenario of ‘double catastrophe’: first there is a nuclear war, causing temperatures on Earth to tumble. Then comes the second blow, when said war disables the system for stratospheric aerosol injection and temperatures bounce back.[97] ‘It would be global frost followed by global furnace.’[98] The one-two punch would leave humanity down and out. (Some would surely label this ‘collapse porn’.)[99]

But the series of events would hardly need to be that extravagant. Imagine someone ascending to the presidency of the country in charge of the planes. This individual has an erratic and careless character and prioritises his own urges over everything else. He is immune to reason, dismissive of climate concerns, suspended in his own alternative universe and a member of a class well insulated from resource shortages. He surrounds himself with yes-men. On a whim, he decides that the cost of geoengineering is unjustified; he grounds the fleet. Pilots are sacked, sulphur stocks liquidated, ground operators forbidden from continuing to support colleagues in allied places. There is outrage, protests, concerned calls from other world leaders; but this only strengthens our individual’s resolve. The opposition proves too weak and divided to alter the facts on the ground. Now imagine more than one such character winning elections in countries upholding the airborne shield … As apocalyptic as it might be, the termination shock could be switched on through humdrum twenty-first-century politics. We shall inspect more such scenarios.

The second category would be endogenous: an end caused not by some monster that enters but by the playing out of geoengineering itself. If the side effects become unendurable, ‘a possible decision would be to terminate the deployment altogether’.[100] The possibilities are then as infinite as the side effects. It follows that the law of their tendency to rise *points in the direction of the termination shock*. There is a dialectic through which the progression of the law drives the probability of the shock higher, potentially sky-high.[101] All that would be needed in the year 2130 would be for one actor, powerful enough to turn off injections, to perceive some number of side effects as more pressing than the prospect of global heating, the memory of which would by then have been suppressed for a century. Exogeneous and endogenous factors might blend: terrorists could be

motivated by a grievance stemming from a side effect.[102] So could an impulsive president. This indeed is the story that unfolds in Stephenson's novel: India and China, left out of the club of elite geoengineers, become suspicious of the scheme and apprehensive of its side effects (at that point still hypothetical). India sends a covert mission to Texas to sabotage the main sulphur cannon, while China launches an all-out invasion of Papua New Guinea to silence a second and seize the main source of sulphur.[103] The fiction here cuts all too close to the bone. Wars, as we shall see, are among the conceivable outcomes of shooting sulphate into the sky.

The risk of a termination shock is thus immanent in the very technology of stratospheric aerosol injections, as in all other geoengineering schemes: if the plastic sheeting over the African deserts were to be removed, the heat would stand revealed in an instant.[104] Any object at the Lagrange point could be in for exogenous disruptions. Space debris might slam into it. Solar storms could burn through its fabric. Sails, drones, a parasol, a dust cloud could drift out of position and float away; if tethered to the earth, a shield the size of Saudi Arabia or two can come crashing down on it.[105] None of these technologies would put chemicals in the atmosphere. One segment of side effects would thereby be avoided – a benefit of the astrophysical approach – but the darkness is here even deeper, the unknown unknowns of greater number, possible repercussions for life on Earth, spanning everything from vitamins to winds, ungaugable.[106] If a swarm of drones does too much damage to such life, it might have to be called back to Earth (or shot further out in space). Marine cloud brightening has its own appendix, of course – any technological arrangement for hiding the accumulation of CO_2 through the diminution of sunlight would build up the danger. For any, this danger grows larger still if emissions persist. And there are plenty of reasons to believe that they would.

16

The Antinomies of Dimming the Sun

The safest way to lock cataclysm into the trajectory of geoengineering would be to burn more fossil fuels under it. If injections *substitute* for mitigation, they are bound to generate malfunctions and constantly rising side effects and hasten the shock: but just as in the case of adaptation and removal, this was how they were originally conceived. Geoengineering was proposed as an alternative to quitting fossil fuels, a doorway into a parallel universe where these could be extracted for as long as anyone would want to. It made its first appearance as a climate solution in a 1965 report to US president Lyndon B. Johnson. The authors ventured that 'climatic changes that may be produced by the increased CO_2 content' of the atmosphere could be favourably dealt with by 'spreading very small reflecting particles over large oceanic areas', so as to increase their albedo. Or one could stimulate the creation of reflective high-altitude cirrus clouds.[1] The report never mentioned the possibility of tackling emissions. Albedo modification was presented as the sole available option for dealing with the problem – the ultimate substitutionism.

The honour of first suggesting sulphate aerosols is commonly attributed to – uncommonly – not an American but a Soviet scientist, Mikhail Budyko, who sketched the idea in 1974.[2] He did so 'on the premise that it was not possible to prevent rising levels of CO_2 and energy use in the short- to medium-term'.[3] On this particular premise, injecting sulphate aerosols presented a more realistic alternative. The idea first appeared in the Western bloc in the very same year, in an article in *Science* that noted how 'the increased use of fossil fuels' steadily builds up the CO_2 concentration. The

authors, who failed to devote even a single word to the option of cutting back on fossil fuels, worried about the climatic consequences: so 'why not inject enough of the right kind of particles into the stratosphere to counteract the warming? Perhaps a fleet of supersonic transports could help here, since they could create a kind of "stratospheric smog" at about the right level.'[4] This might have been a case of simultaneous invention on both sides of the iron curtain.

In the West, the corporation then known as Esso – today, ExxonMobil – discovered the promises of weather modification technologies already in the 1960s, focusing first on how to seed clouds and make more rain fall. (The preferred method was to spread byproducts of petroleum in the atmosphere.)[5] Starting in the mid-1970s, primitive fossil capital in the US also began considering stratospheric aerosol injections to cool the earth. A man who went by the name of S. S. Penner headed, in addition to a 'fossil energy research working group' at the Department of Energy, a research centre funded by the Gulf Oil Foundation dedicated to improving 'the viability of shale oil, coal liquefaction and other fossil fuel technologies'.[6] This S. S. Penner penned an article that laid out the rationale for particle-shooting planes. 'Continued combustion of fossil fuels' might cause 'disastrous' alterations of the climate; but the cost for replacing such fuels would be more unacceptable still. 'Careful assessments must be made of alternative global measures that do not require curtailments of fossil-fuel applications.'[7]

Of considerably greater stature and influence was Nordhaus, the wonderful man with whom we have already bonded, one of the first to be enamoured with solar radiation management.[8] Particles might be sent into the stratosphere in a variety of ways, including the use of '16-inch naval rifles' or by 'tuning the engines of aircraft to burn somewhat richer than normal'. It would be superefficient: 'One estimate finds that 100,000 kilograms of carbon can be offset with 1 kilogram of particles. That's real leverage!'[9] The year after these words were penned, in 1992, following the Rio summit, Nordhaus published an article in *Science* making the same substitutionist case. Phasing out fossil fuels would destroy growth and so should rank as the worst possible option (ideological support for the refusal of the Bush government to countenance such measures at the summit). Geoengineering would be of 'enormous', indeed 'mind-numbing'

superiority. Nordhaus considered it ‘costless’ to the world economy, plus far more efficient in providing benefits for the climate than any emissions cuts could ever be: optimisation ensured.[10]

We are now back in the moment when the basic coordinates were formed. Also in 1992, Nordhaus co-authored a National Academy of Sciences report on policies for dealing with climate. Unlike its predecessor from 1965, it considered all options then on the table, geoengineering one of many, mitigation included. In characteristic vein, it concluded that the former was worth examining in more detail, because ‘efforts by societies to restrain their greenhouse gas emissions might be politically infeasible’, whereas geoengineering appeared ‘much less expensive’. The National Academy stopped short of endorsing deployment but recommended more ‘research and development projects’ – not quite the rousing calls of the early 2020s but a starting signal for some of the earliest explorations.[11]

One who listened attentively was Edward Teller.[12] Best known as the inventor of the hydrogen bomb, Teller was a long-standing advisor to the Pentagon with direct access to the White House and so a figure not to be taken lightly. ‘In the story of geoengineering’, journalist Jeff Goodell writes in *How to Cool the Planet*, ‘no one looms larger than Edward Teller.’[13] As one of the earliest advocates for geoengineering in the West, his career is unique in that it spanned both the mid-twentieth-century efforts to modify the weather and the advancement of stratospheric aerosol injection. A true creature of the Cold War era and believer in the unbridled power of human engineering, he can be seen as one of the earliest representatives of the hardcore technological approach to dealing with climate breakdown.[14] And he espoused the cause of capital protection with a zeal typical for the moment: any reduction in the use of fossil fuels over the coming decades would induce economic losses and ‘major conflict’.[15] Scattering sulphates or other particles would produce the same or a better effect at less than 1 per cent of the cost. Indeed, Teller was adamant that if one took seriously the UNFCCC’s call for cost-effective climate policy, then ‘technical management of radiative forcing of the earth’s fluid envelopes, not administrative management of gaseous inputs to the atmosphere, is the path *mandated*’ (both emphases in original).[16] Why do the hard and tedious work, if you could just push the equivalent of a nuclear button and get it over with?

The lineage from Nordhaus and Teller to Keith and other twenty-first-century scholars of geoengineering passed through the figure of Lowell Wood, a student of Teller, also specialising in nuclear weapons. In the 1990s, he became an evangelist with a growing audience. He was as blunt in his substitutionism as any of his peers. ‘Mitigation is not happening and is not going to happen,’ he quipped at a NASA meeting on geoengineering.[17] ‘We’ve engineered every other environment we live in – why not the planet?’[18] Any risks were exaggerated, any concerns trumped by the superior attraction of a sulphur shield.[19] Keith, in attendance at Wood’s talks, appears to have been impressed and took much the same line: it was ‘very unlikely’ that emissions would be cut, because countries just didn’t want to collaborate – a ‘pragmatic reason to consider geoengineering’, which required ‘fewer cooperating actors’.[20] One agent would be enough to administer the injections. As late as 2000, Keith still compared mitigation with geoengineering like a customer deciding between a train ticket and a plane ticket for getting from A to B and finding the latter much better, because much cheaper.[21] Geoengineering would not so much buy time for mitigation as freedom from it.

Concomitant with the sewage ideology of DAC was thus the development of the cover-up-your-shit ideology of geoengineering; substitutionism was the core of both. Proponents would be upfront about the fact that ‘geoengineering and emissions reductions are substitutes’, and the perception spread that this was indeed how authorities on the former regarded it.[22] ‘A Cheap and Easy Plan to Stop Global Warming’, said a headline in *MIT Technology Review*.[23] Mused Sir Richard Branson in the run-up to COP15 in Copenhagen in 2009: ‘If we could come up with a geoengineering answer to this problem, then Copenhagen wouldn’t be necessary. We could carry on flying our planes and driving our cars.’[24] (It turned out that Copenhagen, as a metonym for cutting down on planes and cars, was not necessary anyway, but that is another matter.) Around this time, primitive fossil capital still made some effort – though never massive – to promote geoengineering, through various think-tanks and research centres in its pay.[25] But then two things happened.[26] Somewhere between Copenhagen and Paris, the big Western oil companies retreated from the research frontier and left it to develop on its own. And a kind of shame began to surround the notion of substitution.

From substitution to combination …

Substitutionism posits geoengineering and mitigation as two equivalent means for reaching the same goal: if you choose one, the other becomes redundant. But when the science of the former matured, this position became untenable. Pumping out CO_2 plus SO_2 on top of it came to be regarded as 'a clear death spiral'.[27] The law of the tendency of the side effects to rise (widely recognised in substance) and the termination shock (all but universally dreaded) together made it abundantly clear that solar radiation management without decarbonisation would be a recipe for catastrophe deferred and then ignited with terrible intensity. In the early twenty-first century, the men who thought about geoengineering began to do so differently: as a *complement* to mitigation. There was no other way to save some sanity and dignity for their enterprise.

They were all men, all white, all active in the US, facts that cannot be brushed off as trivial.[28] Apart from Keith, their maven, there was Wake Smith, Gernot Wagner, Jesse Reynolds, Douglas MacMartin, Ben Kravitz, Peter Irvine, Joshua Horton and a few others, who constituted a fairly tight-knit cohort of like-minded scientists. They were not maniacs or Pollyannas or Cold War warriors itching for the bomb. Unlike, say, Teller or Wood, they went out of their way to distance themselves from the stereotype of the mad scientist. More often than not, they were liberal and progressive, in the American senses of the terms, wary of any association with more irrational currents. An awareness of the risks of geoengineering was integral to their research programme. The core of it was the opposite of substitution, repeated with the devotion becoming of a credo: 'Geoengineering complements emissions reductions' (Keith); it 'cannot substitute for emissions mitigation but it may be a useful supplement' (Keith and Irvine); 'optimal use … is in parallel with mitigation' (Keith and colleagues), the word 'optimal' here being key.[29] In *Geoengineering: The Gamble* from 2021, Wagner seemed genuinely worried by the possibility that someone would treat it as an alternative and passionate about what comes first: 'Most importantly, we must stop burning fossil fuels and putting CO_2 into the atmosphere. Nothing else will do.'[30] The turnaround could hardly have been more complete.

Deployment, the world was now told, will *not* detract from emissions cuts, but rather align with them. Geoengineering will work only if mitigation and removal do. All three have to be advanced in combination. Only then – an absolute axiom, as we have seen – will termination cause no shock: the fire will have gone out by the time the glass door breaks.[31] Now one could readily agree with the normative side of this argument. If geoengineering were ever to happen, it *ought to be* combined with an end to fossil fuels (and a healing of the damage they have done). What Keith and the rest of the cohort argued, however, also had a descriptive side to it: geoengineering *will in fact not* function as a substitute. Turning the old school on its head, they believed that combination would be the factual outcome. The belief came in a strong form – no risk of substitution exists – and a weak – the risk is manageable and no more cause for concern than any other risk in this risk-saturated crisis – and in various intermediate gradations. None of these men would claim that geoengineering cured underlying causes; rather, the contention was that symptomatic treatment of this kind would not subtract from any such cure but go hand in hand with it, assist and smooth it out. It would not trigger a mechanism by which capitalist society sweeps the problem under the rug of a pseudo-remedy.

Geoengineering, on this view, would be but a brief interlude. The operation would be wound up and down, deployed to 'shave off the peak' of overshoot and then retired.[32] 'Ideally, the bought time could be used to decarbonise' – 'ideally', like 'optimally', here being the operative qualifier.[33] The sulphate would sit like a ceiling over a world economy cleaning up its mess. As this more primary task is completed, no demand for ever-increasing volumes of soot will arise. Any risks of undesirable side effects can be managed. All of this is because – and here is the fundamental wager – geoengineering is going to be implemented *in a rational fashion*. Substitutionism thus gave way to rationalism-optimism. Should that make us feel in safer hands?

Reason to pilot unreason

In the best of all possible worlds, we could be getting ready for judicious piloting of the planet through the coming decades or more of climatic

turbulence. But in the best of all possible worlds, we would not, of course, face this predicament to begin with. Here we encounter the first and most basic antinomy of rationalism-optimism and, indeed, of the geoengineering enterprise in general as it was conceived in the early twenty-first century. If rationality had been a reasonable assumption about the way the world is run, there would be no quest to pursue: geoengineering would be nowhere on the agenda. Only the most profoundly irrational drivers could have placed the earth in the trajectory it is currently in.[34]

What Keith and his cohort proposed to do was to enter the cockpit and take us out of the danger zone, at just the right time with the most precise steering. In a seminal paper from 2015, he and MacMartin specified three precepts for how this could be done.[35] Entitled 'A Temporary, Moderate and Responsive Scenario for Solar Geoengineering', it began by taking due note of the side effects, which will rise but not in a linear fashion; there could be threshold effects for inter alia ozone depletion. Geoengineering therefore ought to be done with moderation. It should not aim to compensate for all anthropogenic warming, but perhaps half of it, a sober choice subsequently fed into models to whisk away most if not all negative side effects.[36] Likewise, the sole guarantee against the law and the shock would be to have the technology somehow programmed for an early expiration: it must have an 'implied commitment to measured wind down'. Keith and MacMartin were silent on how that would be ensured. But they hinted at how long 'temporary' deployment could be: on 'the order of a century'.[37] A more ambitious best case had it abridged to 'only several decades'.[38] Lastly, the agent conducting geoengineering must not be nonchalant or reckless about side effects, but must be studiously 'responsive' to any mishaps along the way. It must all be 'done moderately, modestly, and managed well'.[39] It has to be a wonder of rationality, or it will succumb, without fail, to its inner demons.

The question now to be asked is: does this revised, restrained, rationalist-optimist vision of geoengineering have any claim to plausibility? The first thing we must note is that it contains no element of confrontation with the irrational drivers. Neither Keith nor anyone else in this school has had anything to say about the propulsive force working in the depths of the fossil economy or how to shut it down. None of these men has dared to say 'capital destruction'. To the contrary, the notion of 'buying time' is explicitly meant to relax the temporal pressures on mitigation and evade a

sharp showdown with fossil capital. The material base of unreason would be given a reprieve. The fundamental wager, then, is not merely that geoengineering will be implemented in a rational fashion but that it will be so *while the prime movers of irrationality are left in peace*, if only for the time being. Reason would sit in the cockpit while unreason spins in the engine, and this, we can now recognise, is the defining feature of rationalism-optimism: the belief that technologies for sailing through climate destruction can and will be operated prudently *without an assault on the causes of that destruction*.

Only one story of geoengineering has made room for such an assault.[40] In *The Ministry for the Future*, the fleet of sulphate planes is but one response to the Indian heatwave. After this tipping point into total crisis, all kinds of actors strive to stem the heat at its sources with all manner of tactics, from carbon taxes and rewilding via square occupations to, crucially, armed struggle. There arise the Children of Kali. A guerrilla group initially based in India, the Children rapidly spread across the globe to hack and wreck coal-fired power plants, torpedo oil tankers and superyachts, shoot down aircraft, assassinate fossil fuel executives and drone-bomb enclaves of the ultrawealthy. The campaign is so effective that the eponymous Ministry for the Future of the UN takes up sabotage and possibly killings too. Under violent attack from all corners of the globe, fossil capital crumbles. Through causal pathways not always clear, armed struggle is the motor of the transition; and this is how geoengineering is folded into a rational pathway. Because fossil fuels are forcibly ejected from the world economy, stratospheric aerosol injection can become a harmless form of harm reduction.[41]

But none of the rationalist-optimists have, of course, imagined any such plot twist. David Keith has not proposed blowing up superyachts. Kim Stanley Robinson is here the free-wheeling novelist, while the scientists pursuing the technology steer clear of specifying any mechanism for breaking the drivers; indeed, the question is not even asked in their corpus of texts.[42] Their supposedly saner version of geoengineering has a gap in its midst. It is riven with the antinomy of reason as a control room in a world of unreason.

Terror begins with a sigh of relief

Some rationalist-optimists have argued that it would make most sense to deploy before an all-out emergency. Starting early, with tiny doses at first, before conditions are agitated, would allow researchers and policymakers to learn to know the force they are about to unleash.[43] A gradual ramp-up would presumably be desirable from an adaptation perspective as well: if shocking the planet's living systems into sudden warming seems like a rather bad idea, then *mutatis mutandis* the same goes for a sudden cooling. The termination shock is mirrored by the possibility of what one could call the initiation shock; both are to be avoided. But as per gradualism in general, such wishes seem pious. Given the general inertia of capitalist society in the face of the climate crisis and, conscious or unconscious, the widespread perception of geoengineering as a last resort, the most realistic scenario is indeed some singular control emergency that convinces one or several powerful states to throw caution to the wind and go all-in, all at once.[44] A surprising degree of support for it has been documented: when 723 climate negotiators and scientists, working with the UNFCCC and IPCC, were polled in 2019, 52 per cent approved of deployment 'in the event of an approaching climate emergency' (the diplomats and politicians more so than the academics).[45]

The preference might fit the occasion. For all that has been said above, it may still be – or even just appear to be – that unmitigated global warming has worse consequences than geoengineering, *especially* as the two would then be experienced. This would be the juncture when the impacts of the warming strike home with full force and geoengineering turns up as the sole measure for putting a lid on them, while any side effects are as yet only dimly visible. The law of the rise means that geoengineering might seem innocuous initially (at least to some).[46] It might also be eminently effective in stopping the kind of disasters that constitute the control emergency – a hyper-extreme heatwave, say.[47] It could then elicit a big sigh of relief. We have found it! There was, after all, a technology for taking the deadly edge off fossil-fuel combustion! The first encounter with geoengineering may be a passionate love affair (at least for some), rather like the cliché of an injured soldier falling for his nurse. But the nurse, we now know, is an

executioner in disguise, and the more the former is called upon, the closer the latter comes, from which dynamic we can infer a theorem:

The better geoengineering works, the worse it will be. If some fleet of planes really does have the intended effect, its allure will be mighty strong. The operation will have nothing temporary or reserved about it. There will be a hunger for its services, unsatisfied by moderate portions. If geoengineering does *not* work, then it does not work. But if it has the curative properties its inventors ascribe to it and seek to optimise, it will debut as an amazing success, raising in the same proportions the risk of long-term failure: it will give a sense of security.[48] Good initial results will blunt the urgency of mitigation. The prompt of extreme temperature experiences would be dulled.[49]

As for the dominant classes, all of this would – if the empirical record of their behaviour is any guide – deepen their attachment to fossil fuels. They can have only two reasons for breaking that attachment: the manifestations of climate breakdown themselves or the infliction of serious material costs on fossil capital.[50] The former would be softened or suspended by geoengineering, insofar as the control emergency is precipitated by heatwaves, wildfires, storms, hurricanes, droughts, floods or some mix thereof and insofar as geoengineering does indeed work against them. That is the whole point of the exercise: to reduce one of two possible incentives to mitigate.[51] There are moments in the literature when this open secret is leaked. While geoengineering 'cannot substitute for emissions cuts, it *may* substantially reduce the risks of any given GHG emissions pathway', write Keith and Irvine – in plainer terms, emissions would not be so much of a problem any longer.[52] What reason to believe, then, that substitution would not creep in through the back door?

Despite all protestations to the contrary, substitution appears difficult if not impossible to exorcise from the geoengineering enterprise. Sometimes the rationalist-optimists seem to believe that, just by asserting that it is no alternative to mitigation, it will in fact not be used as such. But why expect business-as-usual to give away at the moment of deployment? What would prevent it from surging ahead after the sigh of relief and coopting the sulphate planes as its own guardians in the sky? The case for geoengineering rests on a realistic assessment of the gravity of the breakdown, of it being *too late* for anything else, of, that is, the tenacity of

business-as-usual – which renders the central tenet of rationalism-optimism unrealistic.[53] For all his lack of finesse, Iseman of Make Sunsets here seems to have had a better grasp of actually existing capitalist society. ‘I wouldn’t say we should only do that [geoengineering] after we start dropping global greenhouse gas emissions. Cause, frankly, I don’t know when we’re gonna do that’ – a lucid opening to the death spiral.[54]

In their more clear-sighted moments, even some rationalist-optimists have acknowledged that this is how things are liable to pan out in the observable social order. ‘A balanced approach’ – the ideal combination, plus the temporary-moderate-responsive formula – ‘may well be wishful thinking. If history – and not just climate history – is any guide, it almost surely is. Fundamental forces hold the world back from doing enough to cut CO_2 emissions. Those same forces push the world to do too much when it comes to solar geoengineering,’ Wagner throws up his hands at one point in *The Gamble*.[55] Doing too much here also means doing it for too long. Geoengineering would be susceptible to ‘lock-in’, most obviously if mitigation and removal continue to fail under its ceiling.[56]

But even a brief masking of excess CO_2 might lock in a lasting commitment. Some modelling suggests that a period of one to four decades of increasing emissions under a geoengineered sky would be enough to necessitate that the operation runs for several centuries, lest the built-up extra heat bursts forth.[57] Similarly, Keith and MacMartin once simulated how long geoengineering would have to continue if it were very modest – merely reducing the *rate* of global warming to 0.1°C per decade. In a scenario of stringent emissions cuts, such an unpretentious operation would still need to run for forty years. In the worst-case business-as-usual scenario – the one tracked by emissions trends in the real world – it would be extended to 800 years, even without any ambition to cancel (let alone reverse) the warming.[58] Were that to be the ambition, it would seem physically impossible to let go of the injections within less than a century. Shaving the peak off overshoot to stay at 1.5°C would require at least that much time.[59] Can an operation running for one or more centuries be considered ‘temporary’? It would seem to be enough to make the planet captive to the dialectic of the law of the rise and the risk of the shock.

After the sigh of relief, terror would thus set in. Unless in complete denial – a factor we shall soon examine – society would be aware of how its

survival has come to depend on a flimsy stratum of sulphate aerosols above.[60] The danger of the termination shock would hang over it like a sword of Damocles.[61] Fear of what could happen if the planes were grounded would fuel them to keep flying, doing more sorties, delivering larger loads, thereby reinforcing the tendency of the side effects to rise and further heightening the ultimate risk, motivating another round of prolongation and so on: a spiral from which there might be no safe way out.

… and back to substitution

The driving force of this spiral would, of course, be fossil capital itself in its dreary familiarity. Beyond new types of aeroplanes and other assorted infrastructure, geoengineering has less potential than negative emissions technologies to generate new lines of commodity production; it does not lend itself to late value form with the same ease.[62] Or can we be so sure about that? Value has a way to infest every practice. According to reports from the early 2020s, ‘there has been a surge in new patent applications’ for geoengineering technologies: capital securing intellectual property rights so it can cash in on any future deployment.[63] Awz Ventures fished in these waters. When Make Sunsets invented ‘cooling credits’, it sought to extend the logic of offsetting to geoengineering: to make up for your emissions, buy the release of a sulphur balloon. Were this to become an actual market – and who could rule that out? – stratospheric aerosol injection would be hitched to emissions just as removal had been, via the tether of credits.[64] Iseman and Song could not sell vodka or perfume like the air miners, but they knew to offer at least one commodity. The first-ever experiment in geoengineering rested on the principle of substitution.

And that principle comes naturally, as it were. There is a tight fit between it and the status quo. If the moment of deployment were to give a ninth life to business-as-usual, it would be but another victory for fossil capital. The rationalist-optimist expectation that the curves would be broken in that moment rests on an underestimation of its obduracy. Put differently, forces of substitution are at work in the deepest base of the capitalist mode of production. What old-school substitutionism did was to express them at the level of ideology. It provided prima facie support for the suspicion that

geoengineering would be used as a surrogate for mitigation, hard to shake off for the second generation of scholars and promoters. Despite their turn to reason and rosy rationality, the older, less scrupulous ideological impulse never really quite died away.

In Russia, the lineage from Budyko was carried on by his disciple Yuri Izrael, whose career path crossed that of nuclear technology: during the Chernobyl disaster, he was the Soviet minister of hydrometeorology. When black clouds of radioactive material started blowing towards Moscow, 'his decision was easy. Make it rain.'[65] Bombers took off from the capital to shoot jets of silver iodide into the clouds; under the minister's guidance, they apparently succeeded in releasing the toxic loads over the plains of Belarus and saving the cities of Russia.[66] After this feat of acute symptom alleviation, Izrael proceeded to champion stratospheric aerosol injection as an alternative to conventional mitigation measures, notably the Kyoto Protocol, which he detested.[67] Any halting of the warming 'by means of reduction of greenhouse gas emissions will take place at a distant date, at least not in the current' – twenty-first – 'century'.[68] Any such halting would be a waste of resources anyway, because 'there is no link between human activity and global warming' – not the last slide between climate denial and geoengineering advocacy, as we shall soon see.[69] Izrael rose on the post-Soviet ladder to become 'Putin's most influential science adviser'.[70] In that capacity, he composed a letter to the president in 2005 to convince him that now was an appropriate time to start loading the stratosphere with sulphur and so reduce temperatures by 'a degree or two'.[71] Although Izrael passed away in 2014, the Russian school of substitutionism remained active.[72] So did its American counterpart.

A figure of note here was Steven Koonin. Chief scientist at BP, soon to be appointed undersecretary for science in the Obama administration, in 2008 he led an expert group on geoengineering together with Keith and some of its other up-and-coming students.[73] The much-respected Koonin made his own views of the matter clear in 2021, when he published *Unsettled: What Climate Science Tells Us, What It Doesn't, and Why It Matters*, his ruminations on decades of work in the higher echelons of policymaking. The book repeats all the usual talking points in the slide from denying to geoengineering: yes the planet is heating up, but it will not be all that bad; a warming of 5°C would have 'little net economic impact over

time’; emissions reductions on any meaningful scale will not happen, and so we should pick only the lowest of the lowest hanging fruits from the tree of mitigation.[74] Koonin is most optimistic about adaptation, which he sees – throwback to circa the 1980s – as the natural response to a changing climate, which will ‘very likely be effective’.[75] But in the exceedingly unlikely event that things go south anyway, there needs to be a plan B, and here the geoengineers still have work to do. Koonin is clear that tricky questions remain unsettled, but there is ample time to answer them: ‘Since we’ve seen in previous chapters that extreme weather events show little sign of an imminent climate catastrophe, there’s time to figure all that out.’[76] Do not rock the boat, and if, at some point, you must jump, the geoengineers will have the right equipment to keep you breathing.

For those who claimed to have left substitutionism behind, a certain bias nevertheless remained: they would expound at length on the specificities of geoengineering but be very brief on the mitigation it was supposed to complement. The credo of combination came across as pro forma. To take but one example, the NASEM report began by declaring emissions cuts the ‘top priority’, a ranking performatively contradicted by a long report that had not a word to say about how they could be achieved.[77] It was only too convenient to claim that geoengineering would supplement cuts without ever specifying what these would look like.[78] What kind of mitigation, exactly – how fast, how extensive, in what form – were these advocates proposing that geoengineering would, in fact, be additional to? Answers to such questions would be crucial for moving out of the substitution trap. It is futile to argue with children that the cheap candy they are stuffing their face with will compete with a wholesome dinner, if one does not have a prior understanding of how much potato and broccoli they would ordinarily eat and at what time they would do so. If no preparation of the food takes place but the candy keeps flowing, talk of a combination risks losing credibility.

The rationalist-optimists themselves would let substitutionism seep back through the cracks and slips in their arguments. Keith and MacMartin knew how pregnant with catastrophe full substitution would be, but ‘more plausibly, SRM [solar radiation management] could be a partial substitute’ for cuts.[79] You should not eat candy exclusively, but it is fine to let it replace some of the dinner. Permanent substitution would be unsavoury, but geoengineering could serve as ‘a lengthy bridge from the present to a low-carbon future’ – as per Wagner, eat candy until ten in the evening, then have

your dinner.[80] Another prominent rationalist-optimist, Jesse Reynolds, relapsed with particular frequency. If geoengineering ends up squeezing out mitigation altogether, it would be 'both rational and net beneficial to humans and the environment', because, on the assumptions of neoclassical economics, the welfare of a cooled climate would be bought at a lower price.[81] Reynolds kept invoking the 'net benefit' from substitution.[82] The real danger is that obsession with mitigation deters from geoengineering, and so on.[83] Through such fissures, the deep forces again leaked out into the open, the rationalist-optimists unable to hold them back even in their own texts.

This inability was coupled with an allegiance to the status quo. 'Must we fix capitalism in order to fix the climate?', asked Keith (as though capitalism were a broken entity like the climate, in need of repair rather than destruction). His answer was no. 'Any serious argument in favour of this proposition must confront the fact that Western democracies have made enormous progress in managing environmental problems over the last half century.'[84] It would be superfluous to list all the errors in this statement; it is sufficient simply to state that if it were true, there would have been zero demand for the services of this same Keith. Wagner was responsible for the following sentence: 'Far from posing a fundamental problem to capitalism, it's capitalism with all its innovative and entrepreneurial powers that is our only hope of steering clear of the looming climate shock.'[85] (A rather terrifying idea, given what is coming out of Californian startups these days). Reynolds doubted that there could be anything valuable about a 'restraint of capitalism'.[86] With such declarations of faith and love, the rationalist-optimists tied themselves to capitalist society as the best of all possible worlds, and the single possible one to boot.

Any rupture with business-as-usual must then be a pie in the sky. 'We suffer from the persistent illusion that we can rapidly accomplish the deep structural change necessary to decarbonise our economy,' Keith affirmed, going on to remind us that 'cutting emissions to zero means replacing a big chunk of the heavy infrastructure on which our society rests'.[87] The imperative of capital protection would sometimes be asserted loudly. Shaving off the peak of the heat would allow 'emissions cuts and adaptation measures to be made in an orderly program of technology deployment and capital turnover, at much lower cost and disruption' than under mitigation at

speed.[88] Trillions of dollars of investments might yet be harvested at profit.[89] Such capital protection is, of course, the deepest force for substitution. If geoengineering were to postpone emissions cuts for many decades more, this would be yet another self-sustaining delay, because even more capital would be poured into fossil fuels in the meantime and the planes would need to be kept circling in the sky: the opposite of temporariness.

We can then make out a sequence shared by all three responses to overshoot. Adaptation, removal, geoengineering were originally conceived as alternatives to mitigation. This was the first moment, decades before the onset of the overshoot conjuncture, when approaches to the looming disasters were debated as matters of theory. In the second moment, all three were reframed as adjuncts to mitigation now widely understood to be indispensable. In the third, as temperatures rose towards and then crossed the 1.5°C threshold, marking a dismal defeat for the pursuit of mitigation, all were pulled back towards default substitution – a retrogression expressed through ideological practices but powered by forces in the base. The closer the three came to material reality, the more they seemed to be shedding the rational garb from the middle moment.[90]

Cracks in the screen of reason

Rationalist-optimists have tended to perceive themselves as besieged by unreasonable people. Critics of geoengineering are ‘driven by intuition, ideology, and pre-existing conclusions instead of empiricism and rationality’, asseverates Reynolds; in the eyes of Wagner, negative reactions are ‘visceral’, emotional, clouded by partisanship.[91] Those in opposition do not honour evidence and logics. Have the rationalist-optimists, then, upheld these virtues of reason? Their programme has, as we have seen, been most doggedly haunted by the substitution problem; but any discussion of it has skirted past factors of capital and state, class and race, gender and technology and instead focused on the abstraction of ‘moral hazards’.

The term ‘moral hazards’ was imported – first, ironically, by Keith – from economics, where it designates a situation in which agents take greater risks because their backs are covered. The untoward consequences of their

actions will be dealt with by someone else. They feel protected and therefore indulge in hazardous conduct. By analogy, geoengineering – even the mere thought of it – would function as an insurance, lulling actors into the belief that they will be buffered against catastrophe and enticing them to keep emitting.[92] This, of course, is the concern around mitigation deterrence – recently the more common term – also applicable to negative emissions technologies.[93] We have argued that sulphate planes are likely to produce precisely this effect at the moment of take-off, but most discussion has instead focused on the period of ideational gestation: the research itself as a decoy leading actors to neglect their duties. Just talking about geoengineering incentivises people to sink deeper into the status quo. The rationalist-optimists here face a damning accusation: your textual production as such makes the problem worse. How have they responded?

Several lines of defence have been pursued, beginning with a pseudo-empiricist objection: because mitigation deterrence cannot be quantified, there is no proof for it.[94] All the data supporting its existence – from the original interest of oil companies to the slippages in the research literature to everything known about how capitalist society operates – count for nothing, because it cannot be counted like a sum of money or column of input in a computer model. Nor can the trauma of the experience of an assault. While powered by material factors to which empiricists and rationalist-optimists tend to close their eyes – the inertia of fossil capital, above all – mitigation deterrence also works through psychic mechanisms, the *image* of future bailouts justifying further inaction. Pseudo-empiricist methodologies will discount any such mechanisms as irrelevant to the climate problem. We shall soon argue the opposite: psychic causation should be given *primacy* in the study of climate in general and geoengineering in particular.

A more popular line of defence, however, has been what is called the ‘inverse moral hazard’. If people get to know about geoengineering, this argument goes, they will be scared out of their wits. The spectre of the side effects and the shock and other unsettling aspects will make them yearn for mitigation so powerful that none of this will ever come to pass. There are empirical studies supposedly suggesting as much: one found that subjects informed about geoengineering were more inclined to buy voluntary offsets.[95] Another fed participants with particulars that led them to support a carbon tax.[96] A handful of other papers – including a strictly game-

theoretical ‘proof’ – lend credence to the notion of geoengineering inciting mitigation, but one can poke holes in them: as we have seen, a declared preference to purchase offsets is hardly a reliable indicator of a desire for emissions cuts.[97] It is rather the opposite. Individual responses to questionnaires anyway do not predict government policy (to say nothing of the reasoning of Aramco or Chevron). But Reynolds believes the contrary. Policy can, in fact, be read off from experimental polls, including policy pursued by dictatorships, because ‘even authoritarian leaders are partially constrained by public opinion’; so if a couple of studies suggest that the public will be sufficiently unnerved by geoengineering to jump into mitigation, then that is how states – all states – will act.[98] The idealism of such an argument merits no further comment. Of greater interest are the contradictions at the heart of this line of reasoning.

Geoengineering, we are now informed, is so good because it is so bad that it will terrify people into dealing with the roots of the climate crisis when they learn about it. ‘That may well be the best use of solar geoengineering today: scare people into wanting to mitigate more,’ contends Wagner; indeed, here is ‘the largest role for solar geoengineering research: not for its own sake, but as a wake-up call for broader climate action’.[99] But this argument also deflates itself. If the main objective of geoengineering is to inspire mitigation, then clearly there is nothing to be afraid of. People who read these sentences from Wagner would, presumably, feel calm, not alarm. Moreover, the ‘inverse moral hazard’ goes against the grain of the highest purpose of the rationalist-optimists – namely, to come up with evidence *about how good geoengineering will be* when deployed. ‘I am confident that we could eventually find “clean” ways to alter radiative forcing – methods that have negligible side effects,’ Keith asserts.[100] In one of the many papers he has co-authored, the danger of pollution and ozone depletion is greatly downplayed.[101] Likewise, Wagner spends much of his book dispelling – supposedly – worries about monsoons and precipitation and oceans and plants, ticking off one side effect after another as overblown, arguing that the purpose of the research should be to ferret out any remaining risks and master them.[102] All of this would obviously pull the rug out from under any inverse moral hazard that may exist. Geoengineering cannot both be so good because it is so terrifying and so good because it is actually benign. Even rationalist-optimists need to

abide by the laws of logic, and if they do not, there is reason to suspect that their relation to reason is more troubled than it appears at first sight – particularly if the gaps and contortions keep recurring. And if not even the most rationalist researchers can stick to basic logic, then why would the operator in charge of the sulphate planes?

Will the rational actor please stand up

When computers are made to simulate the fallout from geoengineering, the identity of the subject is never specified. The models do not tell us if it is the Pentagon or G7 or India or the UN General Assembly or some other body that shoulders the task, but they do assign certain attributes to whoever it is: rationality, above all.[103] Only if the geoengineer is rational can the technology be installed in working order and misuse avoided. The way to 'predict states' behaviour', Reynolds explains, 'is to explicitly model them as rational actors'.[104] This is how things are and ought to be. 'Policy should be *rationally designed* and based upon the central goal of minimising net climate risks to humans and the environment in accordance with society's preferences,' runs a typical antiseptic line; unperturbed by indications to the contrary, the 'assumption of rationality will be maintained'.[105] Other rationalist-optimists have added more character traits. Smith assumes that geoengineering will be 'undertaken by a single, rational, and legitimate global monopolist deployer operating on a not-for-profit basis', with nothing but the noblest of motives.[106] 'Any entity that intends to engineer the climate of the entire globe must act – and be seen to act – purely out of humanitarian and environmental considerations unclouded by aspirations of direct financial gain,' conclude Smith and Wagner.[107]

Where on Earth does it exist? It has never been spotted in the realm of politics from which candidates for injectors could emerge – recall that a major economy is required – at least not in this century. Geoengineering is here placed squarely in utopia, where the wolf lives with the lamb and the leopard lies down with the goat, and occasionally the rationalist-optimists admit as much: towards the end of one long modelling exercise, again co-authored by Keith, the reader is told that 'our centralised, benevolent decision-maker is a fiction'.[108] So the reader had been perusing fiction all

along. This escape from reality is not accidental or tangential to the argument; geoengineering could not be made to seem like a sensible proposition if the subject behind it were irrational, reckless, short-sighted, self-serving, beholden to private pecuniary interests or in any other way predisposed to realise malignant potentials.[109] The modelled world must be sterilised of any such presences and lesser imperfections as well. But by the same measure, of course, geoengineering is driven out of known reality. The assumption of rationality, so fundamental to the case, can be maintained only at the cost of descending into fabulation.

It does not get much better when the rationalist-optimists deal with the side effects by positing a subject that is all of the above plus responsive: the commander of the fleets must monitor developments and adjust injections. If, to take but one obvious problem, a massive volcano eruption were to occur during deployment, doses would have to be swiftly reduced to avoid overcooling of the planet. The subject in charge ought to behave like a captain navigating his ship through a field of icebergs, engaging in 'feedback' as new information is received along the way.[110] Models provide only the crudest of maps. The fully enlightened subject must fill in the details. If bad byproducts materialise, it would be up to him to recalibrate the shots – for instance, parrying overcooling of the tropics by injecting more aerosols closer to the poles, or administering extra jabs in wintertime to keep the seasons in place.[111] But simulations then hint at *other* secondary effects and trade-offs.[112] Greater precision would be achieved if the aerosols were diffused lower down, in the troposphere; but then pollution would spike.[113] Nonetheless, the idea persists of the geoengineered Earth as 'a design problem' or 'an optimisation problem', a machine to be tweaked to perfection by the owner and overseer, varying the magnitude, altitude, latitude and timing of the injections.[114] If one button flashes red, push another.

The first problem with this ideal of successive fine-tuning is attribution: how will the subject know that a particular effect is caused by its actions and not by something else? What would it take, for instance, to establish that an epic drought in the Sahel is induced by the ongoing geoengineering, rather than by some teleconnection to residual underlying warming or natural variability or other 'noise' in the system? It might take years to find out. Hence the subject would also have to possess the virtue of 'extreme

patience'.[115] It would need to be impervious to all kinds of pressures from those who would instantaneously attribute this drought or that flooding differently. And that is still not the end of the requirements.

Because so many parameters are perturbed – not only temperature but precipitation, humidity, surface energy balance, quality and quantity of sunlight and any number of regional factors correlating with any of these – a geoengineered Earth would be a computational apparatus tending towards infinite complexity.[116] The ideal is that the subject in question, whoever it is, would exercise 'improved control over more aspects of the climate system'.[117] One after the other, they should be integrated into the calculus; perhaps the fine-grained details of Californian or Congolese climate will eventually be amenable to administration from the sky. And if sulphate injection is not perfectible on its own, it could be supplemented with marine cloud brightening or some other technique of manipulation in what is referred to as 'cocktail geoengineering'.[118] The planet would be set up for 'an infinite regress of further interventions', in the words of Mike Hulme: the defects of Plan B patched up by Plan C, then Plan D, Plan E and so on.[119] 'All unstable processes we shall control,' in the prophetic words of John von Neumann of the Manhattan Project – one more scientist who pioneered both nuclear bomb development and the notion of climate mastery.[120] But total domination of nature is going to be elusive.[121] Every concrete step towards it, however – and attempts cannot be ruled out – raises the demands on the subject: it would have to be not only rational, legitimate and altruistic but also patient and all but omniscient. Impulsiveness and ignorance would wreck the machine in no time.

Geoengineering here stands out from every other instrument in the repository of climate politics. Each requires *some* measure of rationality, even the most quotidian and inconsequential among them: to instal a LED light bulb, the subject must know how to unscrew the old wasteful type and where to dispose of it. But this act cannot strangle the Indian monsoon. Replacing coal with solar or meat with a vegan diet likewise comes with demands on sensibility. Agents of the transition would need good judgement in spades. But nothing they could do has the potential to wreak the kind of havoc geoengineering can, and so they can be fallible mortals and need not be gods. To take an obvious analogy: one could easily use kitchen knives to hurt people; employ enough malign dedication and you

could cut down quite a few. But flood a country with machines guns and the demands for sobriety and self-restraint take on a wholly different scale. If unfulfilled, you would get a situation like in the United States: senseless massacre following senseless massacre. The nuclear bomb of climate politics, geoengineering has the capacity to alter the climate on Earth faster than any other technology *and* blast it to smithereens, which means that it necessitates a rational actor sui generis.[122]

Who could this possibly be? One rationalist-optimist of lesser prominence has a proposal: the IPCC. 'Pre-existing scientific bodies, such as the Intergovernmental Panel on Climate Change, possess large credibility, predisposing them toward an oversight role,' and 'states will be receptive to the scientific body tasked with the monitoring of SRM implementation.'[123] Of course states will listen to the IPCC! Or, on second thought … had they been inclined to do so, there would have been no need to contemplate geoengineering in the first place; for all its gradualist errors, the Panel has always recommended states slash emissions. It is because they did not care to follow this advice that sulphate planes are approaching the runway. One more iteration of the basic antinomy, the belief here is that scientific authority will save the day for geoengineering and ensure responsible deployment – but this is a fairytale world, in which we would never have had, for example, all the excrescences of offsetting and extravaganzas of the startups. The Make Sunsets of this real world rather suggest that would-be-geoengineers won't give a tinker's damn about 'pre-existing scientific bodies'. The disconnection between rationalism and reality is here too wide for comfort.

Some scholars occasionally feel the dissonance. 'Of course, we don't live in a rational world,' Wagner would add as postscript to a sanguine thought experiment; or, 'there is no such thing as "rational" climate policy in the real world'; or, 'political actors aren't always that responsible and rational.' On the one hand are the idealised model settings, on the other 'is the real world, governed by political whims and forces', the world where 'vested interests dominate'.[124] As discoveries go, this one is belated, but it marks a significant concession from the rationalist-optimist camp: once geoengineering is placed in reality, its home is in hell rather than heaven. What if this is treated as more than an afterthought? What if the irrational ways of capitalist society are not an extra parameter to acknowledge in the

end, but the point of departure for understanding the very enterprise of geoengineering itself?

17

Towards a Freudo-Marxist Theory of Geoengineering

There is now a budding – to call it ‘rich’ would be to underrate the subject matter it has to deal with – psychoanalytical literature on the climate crisis.[1] Its foundational insight, somewhat like the equivalent of the greenhouse effect in the physical science basis, concerns denial. The progression of this crisis is *constituted* by denial. It originated in and is perpetuated and aggravated by denial in multifarious forms. In a powerful meditation on how it can work, Lee Zimmerman draws on the dream of the burning child, reported by Freud in *The Interpretation of Dreams*: a father watches his feverish child’s sickbed for days and nights on end, until the child dies. The father then moves into the next room, to a bed from which he can see the corpse laid out between tall candles. After a few hours of sleep, he ‘dreams *that the child is standing beside his bed, grasps him by the arm and whispers to him reproachfully: “Father, can’t you see that I am burning?”*’[2] In Zimmerman’s reading, the child’s question captures the essence of the denial of the ongoing catastrophe. ‘Can’t you see that I am burning?’ the red-hot child asks the father, tugging him by the arm, entreating him to open his eyes and intervene before the body is consumed and despairing about his willingness to do so. Is he even mentally present, there at the bedside? Or has he turned away from the trauma in front of him?

The essence of denial, on this view, is the shutting out of a reality too painful to take in: the climate catastrophe is a trauma in motion, and like the father in the eyes of his dying child, people in capitalist society respond by turning away from it. They develop a myriad of strategies for knowing

what's going on and at the same time not knowing.[3] They keep on living as normal, as though nothing deeply troubling were happening in front of their eyes, as though no child were on fire; and *only because* they behave in this fashion can the burning progress towards its end. Had they intervened in time, they could have doused the flames. Such denial is a psychic process at the level of the individual, but above all – on this the literature is in resounding agreement – it is *organised* or *produced*, by material and ideological processes distinctive to a capitalist society based on fossil fuels. Denial is not an idiosyncrasy or private pathology but a certificate of membership in this particular society, a kind of credit card necessary for moving around in it and accessing its commodities and living without going crazy.[4]

The dream of the burning child also forms a starting point for Alenka Zupančič in her essay *Disavowal*; like Zimmerman, she reads it in the light of the ongoing heating. Actual fires now burn across the planet. They are fuelled by the central, inner fire of fossil fuel combustion – from cause to symptom, fire is the element of this crisis.[5] Closely related to denial, the mechanism of disavowal has a logic of 'I know well, but all the same …', on the pattern of the dream of the burning child.[6] But a different reaction was all the time possible. There is in the Freudian oeuvre another dream, mentioned by neither Zimmerman nor Zupančič, that forms a startling counterpoint to that of the burning child. It appears in perhaps the most (in)famous case history, of Dora, who tells Freud:

> First dream: *There is a fire in the house*, said Dora, *my father is standing beside my bed and wakes me up. I dress quickly. Mama wants to save her jewel-box; but Papa says: I don't want to burn with both my children because of your jewel-box. We hurry downstairs, and as soon as I am out of the house I wake up*.[7]

One thing about the long heat is reasonably certain: the longer it goes on, the sharper the light thrown by this fire, the more artefacts of human culture will be reinterpreted as concerned with it. Insofar as no limit is imposed on the heating, it will consume every text. From Mr Creosote to Dora – not to mention the Hegelian–Engelsian laws of dialectics – everything will be reread as one more story about the fate of the biosphere, if only in a vaguely oracular register.[8] The veil is stripped from the latent content of dreams. The unconscious of the fossil fuel era emerges into visibility: Dora had a

vision of what *could* be done to get out in time. The jewels in the box are the assets that must be stranded, the capital sacrificed so that people may live. The actual fires of the present allow us to cut through the salacious noise Freud generates around Dora in general and this dream in particular: he tells her that the jewel-box represents the vagina. 'I knew *you* were going to say that,' the exasperated client responds.[9] He thinks the dream is about her impulse to escape sexual temptations in the bed. She thinks it is about a *real* risk of fire: she developed this recurring dream after her family went on vacation and 'arrived in a violent thunderstorm and saw the little wooden chalet, which had no lightning-conductor. So his [the father's] fear was natural.'[10] We can here side with Dora against Freud. The latent content of her dream was the picture of *responsible intervention in the moment of danger*, executed by a subject who would rather let go of jewels than see everyone, children included, burn to death.[11]

We then have two models for behaviour in the moment of crisis delineated (unconsciously) by Freud. And there is no doubt which of the two capitalist society has elected to follow.

Classes of denial

Denial is protean enough to embrace all classes. It can unite rich and poor. It can be exercised by the most villainous personifications of fossil capital as well as the most innocent subalterns at the base of the pyramid. It can cloak the crime and the failure to do anything about it. As for the former, a sense of omnipotence breeds a refusal to acknowledge an external world that belies it through limits. Sally Weintrobe, a pioneer of psychoanalytical climate studies, has emphasised this aspect: people on top of the pile cannot own up to a crisis resolvable only by them stepping down, and so 'they live in a bubble-like psychic retreat from reality.' To those who feel entitled to the gifts of the fossil economy, the full reality of climate breakdown is 'anathema'.[12] There is in this type of denial a salient callousness or, as Adorno would have it, 'coldness, the basic principle of bourgeois subjectivity' – the father as cold onlooker.[13] Dominant classes, of course, have a renowned capacity to turn on the 'blindness of the seeing eye' (Freud) when faced with the suffering that they themselves cause.[14] Indeed,

as Henrike Kohpeiß has argued in an elaboration on Adorno, coldness is the 'affective technology' constituting the bourgeois subject since the time of slavery: a ubiquitous technique for 'withdrawal, distance and targeted disengagement', for 'sustained social indifference', for the 'refusal or incapacity to be susceptible to suffering', without which capitalist society *in toto* would cease to function.[15] The bourgeois subject has had to ignore generations of burning children to maintain 'ownership of the earth forever and ever'.[16] He would rather consign children than jewels to the blaze.

To this venerable disposition was added a historical contingency and conjunctural coincidence. On the heels of the fossil fuel frenzy, the world witnessed a genocide. In many respects, it was a genocide unlike any other – above all, livestreamed for everyone to see; documented in real time; available for ocular inspection at the tap of a screen. 'It's like we're watching Auschwitz on TikTok. Had there been YouTube and Instagram and TikTok around Auschwitz, this is what we would have seen: people burning alive,' remarked Gabor Maté (himself a Holocaust survivor).[17] It was also a genocide atypical for being so loudly and proudly advertised.[18] It was exceptional in that the US, the highest pinnacle of capitalist state power, directly participated in the act.[19] In these respects, the Gaza genocide brought the scenario of the burning child to a new level of literal confirmation, when children – systematically targeted as such – actually burned to death in full view of people comfortably reposing in the next room, located one step to the north. Can't you see that the children are burning?

Subjects of power in that northern room responded by turning on the blindness of the seeing eye: denying that a genocide was taking place, while supplying every kind of ammunition required for executing it. The effects were bound to be felt by others than the people here singled out for destruction. In its peculiar constitution, the Gaza genocide marked a step change in the normalisation of the burning of children and other innocents in the global South. It taught the art of bourgeois coldness to a generation of northerners just now entering the overshoot conjuncture. Denial, as the mask of complicity, was distributed more widely and densely than ever before, and it would be worn in other settings.[20] Plenty of observers had the sense that Gaza broke a limit, with repercussions at the species level – among them Isabella Hammad, writing in early 2024: 'Somewhere recently

humanity seems to have crossed an invisible line, and on this side naked power combined with the will to profit threaten to overwhelm the collective interests of our species.'[21] Or, to paraphrase Marx: capital marched this species deeper into the fire while dripping with Palestinian blood and soot.

The same psychopolitics is then applied to the reality of heating.[22] The bourgeois subject puts its well-honed and recently updated affective technology to work and re-enters a state of denial. If this is a mechanism defending against trauma, it would be the trauma of losing fossilised privilege – or capital destruction, the forfeiture of the jewels.[23] Like mitigation deterrence, such denial resists quantification. But its empirical footprint is large enough to cover the planet. There is a fairly famous photograph that deserves iconic status, depicting three golfers – calm and composed, to all appearances – putting while the hillside behind them is aglow with fire.[24] Taken during the 2017 wildfire season in the Pacific Northwest, the shot captures the bubble-like retreat from reality as it approaches bursting point: should we pack away our golf clubs, just because the world around us is burning?[25] A talk show host for a Canadian golf programme chose these words to accompany the picture: 'So many natural disasters, poor people in Houston, poor people in Florida, it also continues in Oregon and the west coast of Canada, the wildfires – and look at these guys, they are finishing their round, maybe 600 or 700 yards away from this fire. They have to be … absolutely … insane.'[26] But this is an insanity that rarely raises eyebrows, a psychopathology at one with life as such for dominant classes. It became spectacular in the golf photo because it was caught in a moment at once overly typical and untypical.

More commonly, the fire rages at a distance. The burning child typically resides in the global South and can be regarded from a safe room – noticed, neglected, forgotten without risk. But in the overshoot conjuncture, those children will multiply and the burning come closer. In June 2024, more than 1,000 pilgrims performing the *hajj* succumbed to the scorching heat, the mass death concentrated among poor devout Egyptians who could not afford the official permits and the air-conditioned spaces that come with them.[27] Death during the *hajj* will sweep up more and more such pilgrims; and yet Saudi Aramco proceeds with its capital expenditure as though nothing is happening.[28] On the other side of the fossil economy, in the same month, twenty-four people attending a rally for Donald Trump in Las Vegas

required medical treatment because of searing heat. From the stage, the presidential candidate noted that ‘it’s 110 [Fahrenheit], but it doesn’t feel it to me’ and turned up climate denialism and fossil fuel chauvinism to levels higher than in his first campaign.[29] Playing golf while the hills burn (metaphorically or literally) looks set to become an ever more common practice during the overshoot conjuncture, the bourgeois subject working overtime to maintain its coldness in the heat and uphold denial. This was the thrust of the offensive early in the second Trump presidency: denial as aggressive praxis and ideology, such as when the laboratory connected to Mauna Loa, the observatory where the atmospheric CO_2 concentration had been measured since 1956 – home of the Keeling curve, following its staggered rise straight up to the leap of 2023 – was slated for shutdown.[30] These were eyes actively closed, curtains drawn before the sight of the burning child, the man pulling the cords the golfing president himself.

But the people most utterly deprived of any similar privileges might have reason to slump into denial as well. For them, it is the *powerlessness* that is so agonising. They, or rather we, ‘find ourselves overwhelmed by the magnitude of the crisis, and by the enormity of the power and money arrayed against those who want to turn a corner to keep our planet livable for all’, Donna Orange observes.[31] Here the trauma is helplessness – the father genuinely incapable of helping his burning child, in possession of no means for intervention and unable to bear the pain of recognising it. He cannot confront his own failure and so turns away. Insofar as the overshoot conjuncture marks the victory of fossil capital and the defeat of everyone who has tried – or even just entertained the thought of trying – to take it on, confirming an inadequacy too serious to bear, it will also provide further grist to the mill of subaltern denial. If you see the child in flames but are in no position to do anything about it, how do you keep living with yourself? Between these opposite class positions of denial, as it were, there are all sorts of intermediate locations and articulations, coming together in a society-wide psychopathology of everyday life. ‘In the minds of the subjects, too, a bourgeois society will choose total destruction, its objective potential, rather than rise to reflections that would threaten its basic stratum’ (Adorno) – basic here in the most material sense.[32]

Denial, then, is a structural condition in a capitalist society making its way towards unmitigated breakdown. The literal denialism of the far right,

still in possession of a bright future, is the crystallisation of this condition.[33] But denial encompasses a much wider set of practices than crowds hooting about climate hoaxes and frauds. More prevalent may be its interpretive form: climate change exists, but it is not much of a problem. More universal still is the implicatory.[34] Here the father does not say anything to deny or downplay the fact that the child is burning – he merely *acts* as if it were not happening, standing there beside the bed, his attention focused elsewhere. Perhaps he just goes about his day. Maybe he occasionally fiddles with the air conditioner. He might give the child a painkiller; but under no circumstances will he initiate the capital destruction that alone can stop the burning from continuing to its end. From this posture, all kinds of technical tactics can sprout. They, too, count as flights from reality.

And flight from reality is the first hallmark of the irrational. Conversely, rationality can be defined, with Adorno, 'as the organ of adjustment to reality – or, as contemporary psychoanalysis calls it, testing reality'.[35] It is the faculty by which the subject recognises and tests reality and adjusts her actions to what she finds there – limits, demands, opportunities – or, the part of the mind that manoeuvres through the reality principle, not ignoring it, not repudiating it. The innumerable antithetical ways of being are the professional preoccupations of psychoanalysis. Mental patients of all stripes 'have turned away from external reality'.[36] 'Every neurosis has the effect, and so probably the purpose, of forcing the patient out of real life, of alienating him from reality,' Freud remarks. The flight spans the gamut of disorders, from the neurotic who 'turns away from reality because he finds either the whole or parts of it unbearable' to the psychotic for whom 'either the external world is not perceived at all, or the perception of it has no effect whatever'.[37] In either case, and in all cases in between, 'we are presented with the task of studying the development of the relationship of neurotics – *and mankind in general* – to reality': psychoanalysis as the study of the fate of the rational in humanity.[38]

That faculty has not fared well recently. Weintrobe quite adequately dates a turning point to the 1980s, the decade when the climate crisis (and other aspects of the ecological crisis) entered the consciousness of capitalist society, never to leave it alone again. It was precisely in this moment, when the crisis began insisting that real limits were approaching, that neoliberalism opened up venues for fleeing. Through deregulation and

privatisation, organised denialism and the cult of egoism, it encouraged an aggressive escape from reality. Nearly half a century later, the cumulative result, Weintrobe goes so far as saying, is a 'collective psychosis'.[39] It follows that the climate crisis *is determined by irrational forces through and through* – and into this forcefield, the rationalist-optimists throw their project, with hopes that amount to giving a hallucinatory psychotic the codes to an atomic bomb and expecting that it will work out just fine. A more promising approach might be to analyse geoengineering as a spin-off of those forces themselves.

From denial to repression

There comes a point when denial shades into repression. Indeed, the two mechanisms are so close and functionally interrelated as to be indistinguishable, in at least some theoretical accounts. Both blot out something disagreeable. Both straddle 'the borderline – never a sharply drawn one – between the normal and the pathological'.[40] The relation between denial and repression can thus be conceptualised in a number of different ways, none of which has won the consensus of psychoanalysts; a fertile attempt was made by Edith Jacobson.[41] She belonged to the second, political generation of psychoanalysts, which might help us to better see geoengineering. Based in Berlin during the Weimar years, they were animated by a belief in the self-evident affinity between psychoanalysis and Marxism, moved in Communist circles, offered therapy to the proletariat and fought the onrushing catastrophe. If they had a theoretical lodestar, it was that psychic processes are subject to the vagaries of history.[42] Jacobson was one of their most brilliant minds – an antifascist activist, feminist, sex therapist counselling working-class youth in Berlin, stubborn enough to stay after the *Machtergreifung*. The Gestapo nabbed her in 1936, but she became so ill in prison that the Nazi authorities let her out, at which point her friends whisked her away to the US; like the rest of her generation, she is all but forgotten today.[43] She is also the author of perhaps the clearest attempt to parse the relation between denial and repression.

For Jacobson, denial targets outside reality. Repression specialises in internal drives. The former works on a broad, 'global' canvas, whereas the

latter has more of a laser focus. Perhaps most significantly, there is a chronological and causal relation between the two: ‘Clinical observations leave no doubt that denial is a more archaic, more primitive, and historically earlier mechanism than repression – in fact, its forerunner’. Denial will ‘normally prepare and assist repression’, which succeeds the former in the struggle against reality and lends it finer precision.[44] It is because denial has ruptured the relation between ego and reality that repression comes into play, as a successor, a more diligent executioner of the task bequeathed. Or, denial is a spontaneous drift away from the disagreeable, while repression sets up a more systematic apparatus to screen it out.[45]

While these distinctions have not been unanimously accepted, the basics of repression are not in much dispute. Here we might return to the founding father. ‘*The essence of repression lies simply in turning something away, and keeping it at a distance, from the conscious*,’ writes Freud, immediately suggesting an overlap with denial.[46] Repression is all about keeping something unpleasant tucked away, out of sight, under the lid. It entails that the subject simultaneously knows about this thing and not knows about it. She does not *want* to know and so pushes the material down into the unconscious, in yet another version of flight from reality: there is some trauma, some painful stimulus that cannot be borne out in the open.[47] We can then hazard the proposition that *geoengineering would represent a materialised and institutionalised repression of the climate crisis*.

It all begins with a moment of danger. ‘The Ego guards against this danger by repression.’[48] Called forth by a drive internal to the ego, a real external menace is now breathing down its neck. A clash has arisen between drive and reality that is dangerous to the ego, who reacts by ‘freeing itself from the contradiction’ through the act of flying away: repression, Freud stresses, is ‘an attempt at flight’.[49] (One is here tempted to see the aviation technology of geoengineering literally fulfilling the scenario.) In his characteristic blend of psychology and thermodynamics, Freud conceives of the drive as a quantum of psychic energy pushing against the surrounding world; when that energy reaches ‘a certain level of intensity’, the conflict ‘becomes active, and precisely this activation elicits repression’.[50] We recognise here the control emergency and the decision to deploy. This is the moment when the flames leap from the child onto the clothes of the father or when the wildfire enters the lawn and the grass itself

starts burning. Now something else has to be done. To endure, denial must make the leap into repression.

But the repressed energy does not hereby go out of existence. Rather, it stays active down below, bubbling, simmering, exerting unrelenting pressure on the forces above, seeking to break through the lid and discharge itself. Repression cannot be like a volcano that erupts in one moment and goes quiet the next. ‘We should not think of the process of repression as a single event with permanent results, as when, say, a living thing is killed and from then on remains dead; repression demands, rather, a constant expenditure of energy and would be undermined if this were relaxed.’ Maintaining the equilibrium requires an equally ‘unrelenting counterpressure’ in an ‘unending conflict’.[51] The injections must not cease; repression is a long-term commitment.

Meanwhile, in this overheated cauldron, the energy must find other outlets. They can appear far removed from the original source. The negated energy succeeds in getting its way ‘by certain roundabout paths’, but not without ‘submitting to some distortions’.[52] Here come the side effects: the fractured regional climates, the lacking rainfall, the diffuse sunlight, the white sky, the blistering sunsets and all the far-fetched rest. The repressed material ‘proliferates in the dark, so to speak, and finds extreme forms of expression’, remote derivatives that can take the subject and those around her by surprise.[53] They too must be dammed up, through new rounds of repression (feedback, cocktail geoengineering).[54] But in the end, all of this, of course, is in vain. ‘A ceaseless struggle is being waged against the repressed, in which the repressing forces steadily lose ground’ (the law of the rise).[55] Ultimately, the defences fail. The more heavily the dam is reinforced, the greater the pressure, until there is the inevitable *return of the repressed*: and of this, science knows no better picture than the termination shock.[56] ‘The “return of the repressed” takes place at the fearful turning points of history,’ notes Herbert Marcuse.[57] The research has described in some detail what it would look like.

This correspondence between the structure of geoengineering and that of repression seems nearly uncanny, but it is not, needless to say, perfect. In Freud, the secondary output from the repressed material chiefly consists in fantasies, not exactly analogous to side effects in the climate system.[58] On the other hand, geoengineering almost realises other elements of his model.

Famously, he compartmentalises the mind and likens it to a building with two rooms, a large entrance hall and a drawing room, with a threshold in between. Facing the entrance hall into which impulses stream, positioned on the threshold, ‘a watchman performs his function: he examines the different mental impulses, acts as a censor, and will not admit them into the drawing-room if they displease him.’[59] This metaphor has given rise to heated dispute between psychoanalysts and between them and their critics, as it seems to imply that the mind is inhabited by an extra agent. The ‘watchman’ or ‘censor’ appears to be a subject in his own right, a homunculus inside the human, who can monitor prospective infiltrating forces, evaluate them and block the door if he judges it to be for the best. In a coherent theory of the mind, this kind of presence and activity are difficult to integrate.[60] In our case, however, it is exactly how things are supposed to work out: the geoengineer would be the *Instanz* endowed with intelligence, its extended arms stationed on the threshold to select among the radiation seeking entrance. Something similar goes for another problem in Freudian theory, namely that of initial knowledge. Repression appears to require a ‘traumatic moment’, in which the mind knows perfectly well the danger it will henceforth pretend does not exist. Lucidity must supervene on at least *one* occasion for the flight to get underway.[61] And, again, this is precisely how geoengineering would present itself. To these two outstanding problems in the theory of repression, an empirical solution has now been drafted.

Geoengineering does not address the causes of global warming: it represses it, exclusively and literally. It maps nearly perfectly onto the Freudian model of repression, but the point is not merely the *formal* resemblance or isomorphism. Rather, geoengineering should be seen as a *substantive* instance of repression, by dint of its functional relation to denial. Capitalist society will have moved all the way into the emergency on the psychic fuel of denial, which, beyond that point, must enter into the engines of the sulphate planes. The sole way for it to persist henceforth is to flip into repression: geoengineering is the single available measure by which this society can convince itself that the fire is not happening, even after it has become unignorable. There is no other practical proposition for the long-term survival of denial. And denial resists its own end.

Or, following Jacobson’s temporal and dialectical schema, we can say that if geoengineering follows next, it will happen only because the prior

phase has laid down the tracks for it. *So strong as to drive society into the emergency, denial will also determine the technology for treating its symptoms* (unlike a technology for attacking the root causes). Denial is the 'forerunner', preparing and assisting and initiating the higher phase of repression, with its finer precision and more stable apparatus.[62] Precisely because it is this fuel that has taken society so deep into the conflagration, we should expect its energies to flow over into the emergency response and upgrade themselves into an unrelenting effort to keep the heating at a distance. If we accept that denial is constitutive of the climate crisis, we must also anticipate that it will impregnate geoengineering, which would be merely a continuation, a transmutation of the processes that have brought the catastrophe about. If the control emergency is to denial as the eye of a needle, it – and the rich man – can enter only by actually suppressing climate change through technologies that make up *means of repression*.

What's done cannot be undone

If repression sublates denial and takes it to a higher, more refined stage, it also forms novel symptoms. A classic example of a symptom, in the psychoanalytical sense of the term, would be compulsive hand washing. Lady Macbeth is its tragic heroine. Once her husband has stabbed the king to death, she launches an operation for removing the stain of the crime:

> Go get some water
> And wash this filthy witness from your hand. …
> A little water clears us of this deed.

This appears to be a good idea at first. Blood has been spilled and can be removed. But of course, the drama does not stop with one act of killing. As Macbeth struggles to seize and hold on to the throne, the murders multiply, the sticky substance attaching to sundry surfaces of the usurper and his queen: blood on their daggers, their faces, their hands. The washing of Lady Macbeth takes on the character of a continuous obsessive ritual. In the fifth and final act, a doctor observes that

> It is an accustomed action with her to seem thus washing her hands: I have known her continue in this a quarter of an hour.

And the Lady is caught in the act speaking to herself:

> Out, damned spot – out I say. One – two – why then 'tis time to do't – Hell is murky.[63]

The repressed material has created for itself the symptom.[64]

There is some resemblance between Lady Macbeth and a capitalist society that sends planes into the highest sky – although, of course, the physical sign would be the opposite: pollution not ablution. If geoengineering begins as the urgent treatment of a symptom, it might well slide into *symptom formation*. (The blurring of the lines between the two was, incidentally, highlighted during the Covid-19 pandemic, when obsessive-compulsive hand washing became mandatory and the most classical symptom of neurotic disorder proliferated; Lady Macbeth's 'Out, damned spot' turned into a meme.)[65] The passage from treatment to formation would seem to be triggered by reactions to a crisis. For the Macbeth couple, the crisis is at once moral, legal and psychic: 'I have done the deed,' the husband confesses to his wife, who responds:

> These deeds must not be thought
> After these ways: so, it will make us mad.[66]

The washing seems sensible in the first instance; but it is the escalation of it that marks the descent of Lady Macbeth into madness (of the neurotic kind, at least to begin with). Rationalist-optimists bank on geoengineering as a discreet and politic stopgap measure. But the script of symptom formation points to another twist: the washer/injector becomes unable to detach from the act, bound to repeat it, fearful that the danger will otherwise explode out into the open.

Jamieson Webster points out that repression *needs* the symptom, in which contradictions are converted into corporeal acts. She brings out the materialist character of the Freudian theory: the ego removes herself from danger by inventing a somatic symptom, as in a lady compulsively washing her hands or planes smearing aerosols on the planet. Through such conversions into physical symptoms, the ego frees herself from conflict; but in the process, she becomes dependent on them – obsessively so. Fidelity to

the symptom is her persistent flight. ‘The force of repression creates a new relationship to the way the hysteric relates to knowledge, namely, that *she does not know*, and this not-knowing – far from being a problem – becomes her virtue.’[67] The neurotic agent of ablution/pollution spins into a refusal of the external world. She represses some acts by other acts in the belief that they can be cancelled out. In Freud’s own words, apparently inspired by *Macbeth*, symptom formation is about ‘*undoing what has been done*’.[68] But can that ever be accomplished?

Macbeth himself is the first to doubt that the washing really will have the desired effect.

> Will all great Neptune’s ocean wash this blood
> Clean from my hand? No – this my hand will rather
> The multitudinous seas incarnadine,
> Making the green one red.

The repression exercised through the symptom will merely spread the blood to all corners of the system. But his wife persists, and drifts ever further from reality: ‘You see her eyes are open,’ says a doctor; ‘Ay but their sense are shut,’ answers a gentlewoman. She suffers the blindness of the seeing eye but eventually gives up too, when forced to realise that no amount of washing will in fact remove the deed.

> Here’s the smell of the blood still. All the perfumes of Arabia will not sweeten this little hand. O, O, O!

and more acutely: ‘What’s done, cannot be undone.’[69]

Geoengineering is about undoing what has been done – the recipe, in *Macbeth*, for going off the rails. A Freudo-Marxist theory would not only give a more realistic picture of what this enterprise would mean and what psychic energies it would run on than roseate premises of rationality. It would also imply that a geoengineered world would be *less* governed by reason than one that simply warms up. Repression marks one step not closer to reality, but away from it. Otto Fenichel – spiritual leader of the second generation, close comrade of Jacobson – intimated as much: ‘Anyone who must keep repressed material in a state of repression has to act inappropriately and is handicapped in his judgement and his sense of reality.’[70] All that then remains is the downward spiral.

Saving profit and planet with a flying phallus

If the theory of symptom formation suggests that whoever launches geoengineering will not let go of it easily but will rather develop a neurotic obsession with its continuation, until some shock – the tyrant king slain, the queen killing herself – breaks it off, so does the theory of fetishism. Freud wondered why some people value their sexual fetishes so highly. His answer came from the penis. More precisely, Freud imagined a little boy who discovers his mother's genitals for the first time. There is no penis there. The sight of the missing penis fills the boy with dread, because it seems to imply that his own prized member could be cut off. This thought is too much to bear. To absorb the perception of the absent phallus without succumbing to a paralysing fear, the boy seizes upon some other object, becomes smitten by it and charges it with enduring libidinal energy. A fetish has arisen like a phoenix from the horror of castration. It protects the boy from the possibility and assures him that the penis is still there, relieving him from the implications of what he has seen. The data of the female anatomy do not have to be fully denied – merely disavowed; half-accepted, half-rejected – thanks to the investment in the fetish. It attains immeasurable value.[71]

This is Freud at his kookiest and corniest. The evidence for boys reacting with such fright the first time they spot their mothers' vaginas is apocryphal, to say the least. Phallic monism – both sexes defined by the male organ, in its presence or absence – has its fairly widely known problems.[72] In his classic *States of Denial: Knowing about Atrocities and Suffering*, Stanley Cohen acknowledges this particular Freudian theory as the source of modern thinking about denial, only to ridicule it as hopelessly 'gnostic' and 'obscure'.[73] Yet shorn of literalism, it might hold another key to the psychology of geoengineering.

We have already argued that fear of capital destruction is a form of castration anxiety.[74] In the reality of climate breakdown, the bourgeois subject discerns the spectre of losing his jewels. Geoengineering arises as 'a token of triumph over the threat of castration and a protection against it'.[75] Along the lines described by Freud, it becomes a fetish: a highly valued compromise solution, enabling the subject to register the grim situation *while keeping his precious objects intact*. The ego has been split in two, one

part accurately perceiving how bad the heating is, the other refusing to sacrifice value to this reality.[76] To sustain the refusal, 'he takes hold of something else instead – a part of the body or some other object – and assigns it the role of the penis which he cannot do without.'[77] Qua fetish, geoengineering would inherit much of the cathexis originally belonging to the capital – particularly the fixed capital – whose destruction mitigation would mandate. Because it would save the penis in the moment of danger, it would become a second penis, valued like the first and then some. Substitution is destiny: over time, the interest in geoengineering will not fade but undergo 'an extraordinary increase', since 'the horror of castration has set up a memorial to itself in the creation of *this substitute*'.[78]

Abstruse as some of this might seem, it is part of a Freudo-Marxist theory intuitively graspable by outlets like *Time*: because billionaires hate the idea of losing capital, they will transfer their passions to geoengineering. It could become a fixation. Such reallocation of cathexis has been foreshadowed in texts written long before any deployment. In *The Planet Remade: How Geoengineering Could Change the World*, Oliver Morton, an editor at the *Economist* who has been responsible for its advocacy of the tech, points out that facilities for digging up and burning fossil fuels represent a lot of fixed capital. Investments of such size deserve respect. 'Fossil fuels are built into the foundations of the industrial and economic system, which means cutting [the mere verb suggesting castration] emissions is hard – especially so since the costs of the cuts are concentrated on a powerful sector of the economy.'[79] Fondle the power and bring on the planes. These have the advantage of attracting 'the interest and admiration of wealthier and more powerful men', 'men of human empire', men whom Morton himself admires, above all Bill Gates.[80] The attraction has connotations not so difficult to detect. 'Some see a beauty in these new forms of engineering – the grandeur of holding back great sheets of ice and re-routing planet-spanning currents of air thrills them,' writes Morton, who counts himself among their number: he outlines a pro-geoengineering argument 'from beauty'.[81] We should take pleasure in the planes. 'It is hard not to delight in these newfound tools,' Keith comes clean.[82] Smith is already starting to. 'The SAIL-01 wing geometry would be selected to substantially reduce drag. Check out the cool renderings in Figures 15.1 to 15.3!', he points to images of the planes for readers to salivate over.[83] If this is the kind of

cathexis channelled into them before they have started flying, one can only imagine how intense it will be after take-off.

Rationalist-optimists would squirm and protest: but this is not how humans relate to their machines! They do so with reason! They employ their cool and clear minds! Such an objection would, of course, once again betray how little they know about human beings, particularly the human beings who have created this climate catastrophe. More to the point would be the quip from Adorno: 'In psychoanalysis nothing is true except the exaggerations.'[84] When it comes to the sulphate plane, it really does have an anatomical likeness to the penis. One reason why men – and it nearly always is, as we have seen, men, rich white men, who study and sponsor and support geoengineering – are so fond of this technology might be the way it ejaculates sulphur out of a tube.[85] It joins philanthropy with pornography: the world saved by a perpetual cum shot.[86] This would not be the first time men have fetishised a 'machine-phallus', but it would produce dangers only the atomic bomb has approached. The bomb, however, has existed mostly in a state of dormancy, with only two exceptions from 1945, so far.[87] Sulphate planes would have to fly more or less around the clock, providing so much more surface for cathexis.

But not only the planes can be fetishes of this kind. It is possible to see all the technologies paraded into the overshoot conjuncture, from the *mégabassine* and 'fire intelligence networks' via 'photosynthesis enhancement' to the latest DAC contraption, as so many fetishes charged with the desire to keep the family jewels intact.[88] Each has the function of reassuring the class of owners: and the 'perception of the fetish as a form of convincing reassurance implies that the fetish has fantasy content attached to it', in the words of Alan Bass.[89] Fetishisation of the technological instrument is a repudiation of the registered reality.[90] The subject puts a piece of his own making above and against it and *enjoys* this self-reflecting thing.[91] Most obviously, the plane-penis would be a bodily extension of the male bourgeois self and loved as such; more generally, fetishisation is fuelled by narcissism.[92] The subject wields an object that allows him to imagine that he remains the inviolate centre of the universe, in a process barely distinguishable from magic.[93] It would account for some of the libidinal investment already allocated to the technologies of overshoot management. 'Narcissistic overvaluation, control, and mastery are inherent

to this autoerotic repudiation of increased tension'; and at the time of this writing, no two men illustrate this dynamic more than Donald Trump and Elon Musk.[94] At the end of it lies the ultimate delusion: that of omnipotence.[95]

Repression as repression

If symptom formation and fetishism denote additional layers in the psychology of geoengineering, repression remains its seedbed. Here is a technology for waging war against reality. Insofar as it develops a fetish character, it stems from this belligerence: 'The creation of the fetish was due to an intention to destroy the evidence for the possibility of castration, so that fear of castration could be avoided.'[96] The overshoot conjuncture thus appears to be characterised by the ascendancy of repression. It also extends to the other meaning of the term outside of Freudian theory: the crushing of dissent by means of force. In 2018–20 – the years between the publication of the Special Report on 1.5°C and the pandemic – the climate movement swelled across the globe, and in the European fatherlands of fossil capital, notably the UK and Germany, states treated it with a degree of leniency, even courtesy. Those states had just paid homage to the 1.5°C goal. They were sworn to the ideal of climate protection. After 2020, however, their relation to the movement took a decidedly sinister turn, as they launched what looked like a 'coordinated' counterwave of repression.[97] From Sweden to Spain, Australia to Canada, climate activists were subjected to surveillance, intimidation, vilification, criminalisation and ultra-draconian punishment, such as when five campaigners in the UK were sentenced to between four and five years in prison for speaking on a Zoom call about blocking motorways – the longest-ever sentence for non-violent protest in that country and a sign of the global times.[98] The gloves were off. (By contrast, 'no major fossil fuel executive is known to have been detained for their role in the climate emergency,' the *Guardian* duly noted.)[99] Moreover, the repression seemed to take on a life of its own. Attacks on climate activists occurred across the global North, with a ferocity uncorrelated to the degree of their militancy: even if impeccably faithful to

non-violence and meek in demeanour, they would be treated with the full force of the law. What was going on?

Tadzio Müller, the leading intellectual of the movement in Germany, sketched a compelling theory of this conjuncture of repression. After official *Klimaschutz* had proved an utter failure, with the heating nearing and reaching 1.5°C, states had to disconnect from their pretences. Climate activists were then no longer the children of a shared code. They were reminders of a dereliction of duty. By pointing out how governments and indeed whole societies had reneged on their pledges, they became sources of annoyance, causes of 'negative emotional states' that had to be shut and locked up, mostly simply because no one wants to feel bad about themselves. An activist who merely contemplates to step onto a motorway would now be a pain in the neck. A youngster with a placard in the street became a target of loathing and spite (somewhat analogous to how the perpetrator hates his victim for embodying his guilt). In the early years of the overshoot conjuncture, the treatment of the climate movement in the global North shifted to repression *in both senses of the term*: force as a vector of *Verdrängung*. Militant or moderate, regardless of what the movement did, its mere existence would henceforth reproach the ruling order for its 'fundamental inability to keep its own promises'. Because the subject in the driving seat 'would rather do anything than deal with his own shit', he was now bound to become 'more and more ashamed, more and more repressive and, as a result, *more and more irrational*'.[100] Alternatively, we could say that climate activists pop up as periodical evidence for the possibility of castration. And so they must be destroyed. Here, too, the overshoot conjuncture seems to mark a graduation from denial to repression, in the sequence identified by Jacobson; and if geoengineering becomes an object of more intense contestation – if protests escalate from petitions to disturbances – the two types of repression could be fused more fully into one.[101] The battle of Sainte-Soline gave one indication of what that might look like.

The psychic life of technology

If denial is the psychic crude of this crisis, repression is becoming the high-octane jet fuel; but this raises some general questions regarding the psychic life of tech. We have argued that the Marxian theory of the *differentia specifica* of human technology allows for the influx of psychic processes into its constitution. Because productive forces are first conceived in the mind, there is ample time for them to be shaped by what goes on there.[102] The bourgeois subject – the men (and the occasional woman) who own and control the means of production – can sire forces born with the mark of its inner dysfunctions. When – if – they are eventually adopted and diffused, it will happen at a particular historical conjuncture of capitalist development. We might think of this as analogous to the childhood of a person: a critical moment affecting the technology for the rest of its life. If intense conflicts rage during these early years, they will flow into the ontogeny of the productive force in question and determine its progression through time.

Such a Freudo-Marxist theory of technology would be concrete and conjunctural – different from the best-known essay in that tradition, *Eros and Civilization: A Philosophical Inquiry into Freud*. There, Marcuse suggests that Thanatos, or the death drive, provides the psychic fuel for technological development: an instinct for destruction is extroverted and applied to nature, which humans have for millennia been hacking up, reassembling, slaughtering, trying to control.[103] The hypothesis is sweepingly formulated for all of civilisation. A more granular theory, true to the historicist bent in Marx, would rather look for the psychic contradictions of particular conjunctures and how these are displaced into emergent technologies. Repression, in other words, is not a transhistorical determinant of productive forces; it is merely the defence mechanism called forth by the overshoot conjuncture.

What of negative emissions technologies? At first sight, some of them would appear to fit the theoretical frame of repression as neatly as geoengineering: hiding the carbon away in chambers underground or undersea, from which it might leak in various returns of the repressed. The recurring fantasies about the ocean make for a particularly neat fit.[104] Here the sin can be removed into a space where no law is thought to prevail and no crime to register. But aside from such pelagic repression, there is a problem with the parallel. Any real remediation of the excess of carbon in the atmosphere would, in fact, entail its durable subsurface sequestration. Successful net removal at scale would signify not a flight from or against

reality, like geoengineering, but a genuine resolution to the problem that defines the external world of climate. We have seen that any such success would presuppose early mitigation across the board – but instead, negative emissions technologies are advanced as a magic standing in for them.

Perhaps their psychic profile is less that of repression than old-fashioned denial. Sending kelp rafts into the ocean or playing at some other form of removal can be a way of saying that everything is going to be all right, if it is not already fine; that the bourgeoise is one step away from cleaning up its house; that revolutionary adventures would be supererogatory. Perhaps we should add a fourth category to the tripartite typology: apart from literal, interpretive and implicatory denial, there is the *performative* type. During the siege and destruction of the Shifa hospital in November 2023, the occupation army claimed to be delivering incubators to that facility. In Zionist media, pictures of soldiers loading the devices onto ambulances accompanied statements from the army about its deep care for the civilians of Gaza.[105] Obviously the purpose of this performance was to deny the genocide taking place. If the literal type of denial repudiates reality in words, if the interpretive befuddles it, if the implicatory ignores it in practice by maintaining a distracted passivity, performative denial would respond to reality by *engaging in select actions* so as to conceal what is happening – a denial one step ahead, as it were.[106] One can think of more than offsetting and token exercises in removal as examples. Billionaires recycling their garbage would be another. But if many actually existing practices of removal had the character of incubators being delivered to Shifa, they would also sanctify business-as-usual and thereby contribute to preparing the ground for the next vault: into repression.

Towards sulphur fascism?

That vault has already been prefigured by the ‘men of human empire’ spearheading the geoengineering enterprise. The genius of Keith might lie in his precocious graduation: he began in the elementary school of denial. ‘Economically, it’s not even clear that global warming is all negative,’ he declared in 2006. ‘There are energy executives already thinking about how they could drill for oil in an ice-free Arctic summer’ – hurray, the warming

will give primitive fossil capital even more material to work with. Plus 'people like to go where it's warm, and you are a fool if you think there aren't benefits to a place like Canada getting gradually warmer. It's just not true that the climate we have is automatically the best one – and you have to be straight about this.'[107] Four years later, he was on record making the following statement:

> I'm not sure that global warming is such a threat to human civilisation. I think we have to be honest with ourselves – there will be winners and losers. Some places will experience more productivity. Some people will enjoy warmer weather. This is not to deny or minimise the suffering and hardship that others will experience, especially in poor countries. But the fact is, human beings are a remarkably adaptive species. And I believe that, by and large, people will adapt to the changing climate. If it's just the human race you're worried about, I'm not sure global warming is such a big problem.[108]

Apart from the blatant racism and classism on display here – the distinction between the fate of non-white others in poor countries and that of the human race – one could hardly find a more perfect example of interpretive denial. Come 2024 and the *New York Times* published an extended profile of Keith under the headline 'This Scientist Has a Risky Plan to Cool Earth. There's Growing Interest'.[109] By this time, he had learned to carefully avoid his earlier crude errors. Now he would emphasise geoengineering as a blessing to the poor and quickly recite the line on phasing out fossil fuels. (Although he would still, somewhat paradoxically, deny the science of tipping points.)[110] Keith had moved on from denial to the preparation of the means of repression and was grooming others for the same somersault.

It was easy to make: the most illustrious scientist-cum-denialist of the 1990s, Fred Singer, wrote a paper rehashing all the tropes of climate denial and ended by declaring that *if* global warming turns out to be bad, there is always the possibility of toning down the sunlight.[111] Soon the denialist apparatus of primitive fossil capital would engage in the same kind of kettle-borrowing.[112] Men like Koonin excelled in it, and Nordhaus even more. The latter embraced both removal and geoengineering while dismissing the sum total dangers of warming. It would not be all that bad, the brain behind bourgeois climate economics reasoned. Agriculture would be somewhat exposed, but probably not that much. Adaptation would take care of any woes. Most of the rest of the economy – 'manufacturing, mining, utilities, finance, trade, and most service industries' – would be

insulated from any major impacts ‘over the next fifty to seventy-five years’. For sure, there would be less ‘snow skiing’, but on the other hand, we could look forward to more ‘investments in waterskiing’. In fact, most people would hardly notice the warming, because the daily variations in temperature, over an average twenty-four-hour span, exceed any effect a changing climate would have. ‘The change in temperature while this paper is being read is likely to be greater than the expected change from 1990 to 2090,’ and so the ‘CO_2 signal’ would likely get lost ‘amidst the noisy pandemonium’ of people’s everyday lives.[113] The things one could get a Nobel prize for …[114]

The practice continued into the 2020s, including in a country like Sweden, long reputed to have among the most enlightened and rational policies for climate. After the installation of a right-wing cabinet in 2022, these were systematically dismantled under the supervision of the Sweden Democrats, the denialist far-right party dominating the government and politics of this nation.[115] Handpicked to lend the backsliding some respectability was John Hassler, a professor of economics at Stockholm University, member of the committee that gave Nordhaus his prize.[116] This man had also published calculations purportedly showing that preferred warming levels rested somewhere around 4°C; it was ‘of course optimal to allow some climate damage as long as coal and oil have value’.[117] In the early 2020s, he teamed up with Christer Fuglesang the astronaut to preach the gospel of geoengineering, preferably in the form of sails at Lagrange.[118] He combined this effort with overseeing the new government climate action plan, in which the goals specifying national emissions reductions over the coming decades were scrapped (and more offsets brought in).[119] Sweden thereby produced the writing on the wall: *a far right rooted in climate denial could swing into support for geoengineering*.

But Sweden is, of course, a mite compared to the US; and here, the turnabout has been foreseen and feared for some time.[120] In 2017, Keith acknowledged: ‘In some ways the thing we fear most is a tweet from Trump saying, Solar geoengineering solves everything! It’s great! We don’t need to bother to cut emissions.’[121] No such tweet was posted during the first Trump presidency, presumably to the relief of Keith and his cohort. Why the fear? Because a far-right embrace of geoengineering, a deployment under the auspices of a president or party in programmatic denial, would

spell out *the guarantee for substitution*. It is very easy to imagine someone like Trump making the flip. It would not compel him to revise his literal denial. He would merely need to tweet that it has now actually become too hot up here on stage, for reasons unknown and unrelated to my buddies; but thankfully, we have the greatest-ever tech that can sort it out. It is impossible to imagine him adopting that technology together with radical emissions cuts.

No sooner had Trump been reinstalled than speculation began again: will he do it this time? Two British champions of geoengineering welcomed the scenario. The progression of the heating as such increased its probability: 'Extreme weather will become harder to ignore. Trump could of course downplay any link to climate change but there's a chance this might trigger him to decide emergency action is required.' He populated his retinue with the supermen of big tech – Musk *über alles* – who would have few qualms about it. 'He likes to act fast and is prepared to deal with democratic reactions later. In those circumstances he might feel that we should do whatever it takes to deploy new climate-saving strategies at speed.' With enough spurs from wildfires or hurricanes, these two researchers concluded, anticipating some fresh funding, the forty-seventh president may well instruct the Pentagon to load its fighter jets.[122] Richard Haass, an elder of the US foreign policy establishment, likewise looked forward to geoengineering having a moment in the sun. With Trump back in power, the silly illusion of a transition was finally punctured: 'Fossil fuels will be here for decades to come.' Indeed, the most powerful man on Earth now put the pedal to the metal of their production. 'The good news, though, is that a range of potential initiatives that are consistent with the Trump administration's priorities could still slow climate change' – some muscular adaptation tech (to be overseen by Musk), some tree plantations, some DAC and, above all, the sulphate planes, neither of which would collide with the car accelerating out from the White House. 'Here is a way he can act on it.'[123]

What these commentators chose to repress was, of course, the knowledge of the death spiral: Trump appeared likely to go into orbit precisely because *he would never leave fossil fuels under the ground*.[124] As Keith himself warned during the first act, the sulphate doses would have to become larger and larger and continue for longer and longer and thus activate one side effect after another to keep the lid on Trumpian exhaust fumes.[125]

Rationalism-optimism would not survive one minute of such deployment. If the return of Trump brought geoengineering closer to reality, it could only be in its most death-dealing form: the substitution consummate. But in early 2025, these remained speculations. Perhaps it would rather be the forty-eighth or fiftieth president who would do it. Anyone of a similar bent taking the helm at an even later stage of warming would be still more prone to geoengineering, with the most feared results: the logic was not contingent upon Trump as an individual. It flowed from the power of far-right anti-climate politics.[126]

Such politics rested on imperishable loyalty to the pursuit of maximum fossil fuel production – but not, it is important to note, on denial of the vintage literal form. It could as well segue into the interpretive or implicatory moulds. Already during the first Trump presidency, some members of his administration appeared to move towards a recognition of climate breakdown as a reality, a fact of the world that should be accepted or even welcomed on the way to the last drop of oil.[127] Early in the second, a similar line was espoused by Chris Wright. Newly appointed energy secretary – formerly CEO of aptly named Liberty Energy, the second-largest fracking company in the US – he spoke to the peers of his class fraction down in Houston: 'I am a climate realist. The Trump administration will treat climate change for what it is, a global physical phenomenon that is a side effect of building the modern world.'[128] All eyes will stay on the prize of fossil fuels, Wright ensured his audience, regardless of what this 'physical phenomenon' might bring. Such a position refines – or perhaps complements – literal denial with a recognition of the basic mechanisms of global heating; but it fits the model of implicatory denial, or disavowal, with Zupančič: I know well, but all the same.[129] It is still very much within the frame of the burning child. The father has here steeled himself with such levels of coldness that he can afford to acknowledge that the child is indeed on fire, while proceeding to throw ever-more fuel on her. Perhaps this element of lucidity bespeaks the shift to repression. A regime that embraces climate breakdown as the flipside of fossil fuels is preparing to treat it with something like sulphate planes.

Other unpretty scenarios are then also conceivable. Far-right regimes might see burning children moving their way. The UNEP report on geoengineering imagines a situation where 'mass migration' from the South to the North precipitates a control emergency – 'the most plausible

scenario' for deployment, according to Wake Smith.[130] The non-white hordes would then be pushed back through dual repression. Alongside fossil fascism, there would be sulphur fascism.[131]

Fury or scream

Rationalist-optimists bet that geoengineering will be inaugurated in a moment of civilisational catharsis, in which every flaw and blemish of hitherto existing climate politics is converted into its angelic opposite. But if such politics are afflicted by irrational currents already *before* the warming has turned into an out-and-out emergency, why expect it to come to its senses at that moment? It might well be the other way around: a confluence of avalanches could make judicious policymaking even rarer. The instability might favour trigger-happy demagogues. Initiative could pass to the most ruthless authoritarians – the people who care least about peer-reviewed literature or the sentiments of an Indian population deprived of its monsoon. 'Somewhere in the shadows of stress, the social norms begin to tear.'[132] The irrationalities of the dominant classes and the far right protecting them would then be extrapolated rather than overcome. But what about subaltern classes and any progressive forces that might represent their interests? Would they regain consciousness in crunch time? What would ordinary people feel and think in a geoengineered world or on the threshold of one becoming such? Might reason flourish from below?

All of this is impossible to know in advance, of course, but the factor warrants speculation as much as any other, because any prospect of combination, as opposed to substitution, hinges on revolutionary subjectivity. This much is clear: fossil capital will not die a natural death. It will not go into the night without defending itself. Before or after the onset of geoengineering, capital destruction would require a massive thrust from below. Whether as the Children of Kali or some other incarnation of popular agency, there would have to be a disruptive force on a scale not yet seen, inflicting material costs on fossil capital so injurious that it – presumably under the guidance of some states – would have to be conclusively liquidated. The question then becomes: would a geoengineered

world be conducive to the formation of such subjectivity? Or would it make it even more difficult?

If geoengineering works reasonably well, it will keep the reality of global heating away from the conscious, at a distance. But because this veil of repression would be wrapped around the entire planet, it would also be visible to the naked eye. Sunsets would be reminders. Merely by turning the gaze skyward, at least outside conurbations, one would acquire proof of the procedure. How might people react to such atmospheric enclosure? One scholar of geoengineering, Alan Robock, had the sagacity to raise that question in a classic catalogue of twenty side effects: 'Both the disappearance of blue skies and the appearance of red sunsets could have strong psychological impacts on humanity.'[133] Of what nature? The impacts might be galvanising. One could imagine outpourings of revulsion and fury at this ultimate act of dispossession: not even the sky and the stars available for common appreciation anymore. People might rise up against the tyrannical classes that first stabbed the climate so insistently that it collapsed and then sought to cover up the deed by this disgusting pollution. They might be provoked to mobilise all available force behind demands for the expropriation of fossil fuel property and the restoration of a liveable climate. Perhaps they might even win. Surely that would count as a victory for reason.

Or things could go the other way around: geoengineering could hone the skill of blindness in the seeing eye. Ubiquitous manifestations of wrongness are evidently not a sufficient condition for indignant protest. If people have opted for 'ostrich-like policy' (Freud) towards climate impacts raining down all around them, surely they would be capable of habituating themselves to an engineered atmosphere and accepting it as one more facet of modern life.[134] Catriona McKinnon has speculated that the generation growing up in the decades spanning intense research, launch and early deployment might decry the losses, but maybe their children won't. Acclimatisation could follow. Several decades into geoengineering, 'perhaps only nostalgic "old fools" with "lighted rooms" inside their heads would mourn for lost blue skies and starry nights.'[135] Indeed, starry nights have already been lost: by the mid-2010s, the Milky Way was no longer visible to one third of humanity.[136] Light pollution caused the night sky to brighten by an average of 10 per cent per year by the mid-2020s.[137] Stars were disappearing from sight: and there was little sign of protest activity.[138]

If anything, geoengineering could deepen such resignation further. Perhaps the best way to hide the heating would be to do it in plain sight.

But resignation would be an impact in its own right. So would anxiety. Robock nods at *The Scream* by Edvard Munch, the cliché image of the latter emotion, the vibrating blood-red sunset enhancing the anguish of the wailing figure: a composition possibly inspired by the effects of the eruption of the Krakatoa volcano in 1883 (the blast of sulphate which cut average temperature on Earth by 1.2°C for a year).[139] Of what does the feeling speak? '*Angst*', Adorno lays down, 'is the claustrophobia of a systematised society', a gut response to 'the closed system'.[140] Geoengineering might heighten closure and claustrophobia. Capitalist society is like a 'brick wall' into which people bang their heads; and the wall grows higher and thicker, while 'leaving less and less outside'.[141] The diagnosis fits: the wall extended to the sky itself, there to intensify the experience of powerlessness. It is through technology introduced from above that society integrates its populations ever more tightly and confines them in inferiority. 'The individual is wholly devalued in relation to the economic powers, which at the same time press the control of society over nature to hitherto unsuspected heights.'[142] Is geoengineering likely to herald empowerment? A season of confidence in the self-activity of the masses? Nothing less would be prerequisite to mitigation, hence combination.

White sky and red sunsets would be an index of epochal failure: the ineptitude of the forces taking on fossil capital; the stupefying power of this enemy, certified through a seal in heaven. The reminders would be of repression (quite possibly dual) and defeat. An individual, a subaltern class might feel diminished to the point of nullity under this stratospheric vault – psychologically, a strong activism deterrent. What strains credulity most in Robinson's plot is that the Children of Kali spring into action *precisely as geoengineering gets underway*. Not only would deployment supposedly – as it does in the novel – lessen the suffering that prods climate discontent; it would be a memorial in brick to the unmovable power of the ruling order. In this scenario, a geoengineered world is, to again speak with Adorno, 'one that secretly everyone finds deeply dubious, but it is also one that is so overpowering that people feel they can do nothing about it'; one where the 'incredible disproportion between all individuals, every individual, wherever they might be, and the concentrated power of society' has

increased even further, so that ‘the notion of resisting this agglomerated power seems illusory’.[143] This would not be a formula for revolutionary eruptions. It would rather be *The Scream*.

Affects of such nature could have their own temporal arc. Pace Robinson, the sigh of relief when the emergency is palliated might usher in positive acquiescence, as the first popular science book on the topic intuited: ‘The illusion of control – “Everything’s okay, the scientists have fixed the problem” – could engender apathy at a time when we desperately need to stop pouring carbon dioxide into the sky.’[144] Deeper into the operation, the risk of termination shock might generate late submission. Who would dare to rise up against the powers in the sky, if their coming down to Earth would spell doom? The threat of the shock would then stimulate further repression, along the lines of a client resisting the therapist’s call to lift it: ‘See what happens if I really give way to such things. Was I not right to consign them to repression?’[145] If so, the repression above would indeed be internalised below, while shading back into the original subaltern denial. To the same degree, the return of the repressed would become more inevitable, more frightful.

Everything is a conspiracy

On the other hand, again, there is distinctive potential for politicisation of the weather. For the first time in history, some human giant would have his hands on clouds and rains, air currents and atmospheric rivers. Extreme weather events could no longer be dismissed as flukes, accepted as acts of God or, indeed, deplored as outcomes of global heating. A suspicion might take hold that they stem from the deliberate manipulation: this parching of our fields is your fault![146] Because daily weather would be subjected to intentional control, it would enter the realm of political contestation in a qualitatively different manner. No one raged against the droughts after Pinatubo; few pointed straight fingers of blame after the floods in the eastern Mediterranean in the early 2020s. But the sulphate planes would be *directly* responsible for restructuring weather patterns, inviting another degree of fury.

As we have seen, satisfactory attribution would require painstaking scientific work. Would people meekly sit around and wait for the results? One scholar aligned with rationalism-optimism has identified a potential for mayhem: if bad weather happens under stratospheric aerosol injection, 'the response is likely to be angry and irrational'.[147] One can imagine people traumatised by climate suffering carrying their rage into the geoengineered world and lashing out against the presumed offenders, long before the verdict is in. All sorts of dominant class interests could gain from scapegoating – say, an Indian government deflecting blame for an agricultural crisis onto a Chinese state doing injections.[148] Indeed, an embryonic version of this already played out in the postwar history of weather modification (of which more soon): irrespective of what influence such attempts actually had on meteorological phenomena, backlashes followed, with all kinds of actors demanding compensation for damages caused.[149] In New York City, 169 damage claims were filed in 1951 alone for flooding attributed to a 'rainmaker' the city had hired.[150] Now imagine the stratospheric equivalent of this. An entire sphere of tellurian existence – global weather – would be incorporated into the struggle between nations, classes, left and right; and the result might be, rather than anxious lethargy, an immense volatility. Geoengineering could betoken the saturation of everything with politics. There would be an interminable multiplication of fronts, spanning everything from the very hue of the sky to the nutritional value of the rice served at dinner, all potentially traceable to the decisions made in the control room.[151] Seen from this angle, geoengineering might be the end of climate but the beginning of a history of furious struggles over its manmade successor states. When it's too late, politics would heat up and boil over.

Will it be clearsighted? The less rational and less savoury side of popular engagement with the phenomenon rushed onto the stage already in the early twenty-first century, in the form of the chemtrails conspiracy theory. It held that 'geoengineering' was already very much in progress. Planes operated by some Big Brother or other were secretly spraying the earth with toxic chemicals. According to different renditions, the military, a cabal of businessmen or the shady strata of states were mixing aluminium, pathogens or even desiccated blood into the trails left by aeroplanes – not the contrails gullible brains would perceive, but *chemtrails* – so as to murder unwanted parts of the population, control minds or simply

manipulate the weather.[152] In this internet-driven dust cloud of theory production, ‘geoengineering’ was used interchangeably with ‘chemtrails’; prominent websites had premature names such as ‘geoengineering watch’ or ‘bye bye blue sky’.[153]

All versions were bogus. No evidence existed that any of this was taking place in the real world. And yet a survey undertaken by Wagner and a colleague in 2017 found that 10 per cent of the American population held the chemtrails theory to be ‘completely’ true, while another 20 to 30 per cent thought it ‘somewhat’ true (up from 2.6 and 14 per cent, respectively, in 2010) – in other words, more than one third of Americans saw some truth content in the fable. Conversations about ‘geoengineering’ on social media were totally dominated by the chemtrails, outweighing more factually grounded posts – neutral or critical – by a ratio of more than 4 to 1. ‘Positive portrayal’ of stratospheric aerosol injection ‘barely registered at <1%’.[154] After 2018, furthermore, when the overshoot conjuncture got going, other conspiracy theories – about globalists, vaccines, QAnon – spilled over into online conversations about geoengineering and chemtrails, forming a sea of slop.[155] Typical tweets would read ‘F**k bill gates in the god damn a**hole’ or ‘F**k #HBO #GameofThrones #chemtrails’ or ‘Stop F**king spraying us you F**king Nazi c**s! @BillGates … The weather is controlled. #Geoengineering RIP idiots’, and so on.[156]

By the mid-2020s, this online shitstorm had blown into parliamentary assemblies in the US.[157] Tennessee became the first state to ban geoengineering, following a campaign from Republicans who scoffed at the ‘supposed climate crisis’. But they fretted over chemtrails. A spate of similar initiatives rolled through legislatures, on the model of a bill from a Republican in Rhode Island by the name of Karen – how ironic – MacBeth, who couldn’t take her eyes off the streaks from aircraft. These brainiacs of the Grand Old Party detested government above all. One sponsor of an anti-geoengineering bill was an ultra-libertarian operative in the struggle against taxation, who once supplied weapons to a couple fighting federal marshals over unpaid taxes and spent twelve years in prison as a result. He resolved to take revenge on the system by running for sheriff in New Hampshire, on the following slogan: ‘People are tired of the intentional polluting of our skies. No more geoengineering!’[158]

A self-appointed vanguard in the resistance appeared to be the Church of Jesus Christ of Latter-day Saints, a.k.a. the Mormons. One of their number pushed a ban in the blessed state of Utah, and another explained: 'It absolutely is happening in Utah. We have chemicals and microparticles of aluminum and all kinds of things raining down on us, into our soil, into our water, and we're breathing it into our lungs,' so it had to be stopped.[159] Here climate denial bounced off in a completely different direction. Anti-geoengineering crusaders had often apprenticed as anti-vaccine warriors, moving their freedom fight from one front to the next: 'We went from being dirty germ emitters during Covid, to now we're dirty carbon emitters. And you know, both of these things are false, and they're looking to infringe on our rights.'[160] A far right ever more far-out might thus end up taking any position on geoengineering, including the deduction 1.) global heating does not exist; 2.) geoengineering (that is, the spraying of chemtrails) has been going on for a long time; 3.) those who justify this activity by reference to climate are trying to kill us. One cannot, then, absolutely count on a far right in power to switch to repression.[161] Lucidity might never supervene, no traumatic moment ever register; the denial could just double its wager. One should never underestimate the fecundity of the irrationalities of bourgeois civilisation.

And one here has to pity the rationalist-optimists. They tried to build a ship for stormy waters, but people scaled the walls and pelted the prototype with stones in the belief that it was a fire-spewing dragon: how misunderstood they must have felt. The prodigious popularity of the chemtrails theory – in their own rationalist-optimist homeland the USA to boot – 'renders rational conversations around solar geoengineering and its potential role in climate policy even more difficult', Wagner and colleague lamented.[162] And this even before geoengineering had become a real thing. 'If conspiracists are gyrating now about secret deployments that are in fact not happening, imagine the world's trepidation once they actually are!' Smith exclaimed.[163] Given how Stardust, Keith and others favoured secrecy for the next stages of experiments, the gyrating looks set to speed up. But the trepidation could come without covert operations. Even the most transparent deployment would be an earth-shattering event, likely to arouse emotional storms – of apprehension, disorientation, incomprehension and, of course, again, angst. A launch of this ship into calm waters is hard to

conceive. If irrational forces in politics have submerged geoengineering *ex ante*, we should expect them to follow it *ex post* too.

Indeed, if the thing ever becomes real, the stimulants to conspiracy theories should be more not less potent. Even mentioning the fact that George Soros advocated marine cloud brightening in 2023 feels like dangling a carrot before the nuttiest online warriors. Imagine the fulminations if some billionaire were to be seen behind the nozzles or cannons or planes actually being rolled out anno 2033 (and imagine he is Jewish or Muslim). Populist animus might not be a helpful affective storm. And regardless of the identity of the deployers, the system of injections could itself be conducive to certain psychic complexes. People may get the impression 'that everything is linked up with everything else and that they have no way out' and so develop 'a feeling of being "caught"'. There might be widespread 'insecurity and anxiety'. Such a condition tends to spawn 'paranoid tendencies in people' – who is in charge here, who is running and ruining our lives?[164] If a control room were in fact to be installed and filled with rational air traffic controllers, they might well be under siege from irate and impassioned crowds – the chemtrails theory as another prefiguration. Paralysis and paranoia are co-constitutive.

Pandemonium, then, might be a general psychic result. If so, prospects for rational treatment of the underlying causes – fossil fuel production, above all – would diminish. The apparatus of repression would make people take issue with and bicker over and hallucinate about a thousand things *other* than what brought them into the mess in the first place. That would be analogous to how a patient behaves in therapy, when her symptoms have pushed her to a point of misery, but she cannot face up to its causes; instead she resists attempts at their unearthing.[165] She is exercised by more immediate woes. The repression has buried the trauma under layer after layer of distraction and distortion: and 'one cannot overcome an enemy who is absent or not within range' (Freud).[166] This would seem to be the logical situation in a geoengineered world. In every scenario except for that of mass outrage provoked by the double crime, coming to grips with the primary drivers would be harder, since they would be overlaid by heaps of diversions. There would have to be a whole lot of remembering and working-through to get to the bottom of the predicament.

Mastering the disorder of nature

And yet the geoengineering enterprise is not irrational all the way through. In some respects, it rather reveals a keen sense of reality. The notion of feedback, for instance, outlines an assiduous application of the reality principle: the captain that steers around any snags appearing on the radar. He continuously tests and adjusts his course to the surroundings. Consider this passage from the pen of Smith:

> The high-bypass engines installed on current production airliners, with big front-end fans that route most of the air around the engine core rather than through it, operate very poorly above 15 km, so SAIL-01 [the sulphate planes to be constructed] would utilise medium bypass engines such as the F1118 GE-101 high-altitude turbofan. The engines would be mounted on four pylon nacelles on the wings, and inboard twin pod (two engines) and a mid-span single pod.[167]

However much it might sound like it to the uninitiated, this is not a fever dream or the raving of the mad. These sentences are written in hyperrational code, in the style of a user manual instructing the reader in how to use a machine. Geoengineering research is deeply preoccupied with the material properties of the world: the size of aerosols, the density and dispersal of plumes, the chemical reactions between particles. It seeks a path through thick clouds of stubborn realities, a method that will take it securely to the goal. It scans the shelves for the best precursors, engines, wings, points of injection and other items to be assembled into the most efficient possible hardware.

There are no difficulties in categorising this mode of rationality: it is *instrumental*. The concern is with the means. These must be optimised, so as to provide the shortest road to the fixed and set end. Presumptive geoengineers seek the ‘handling of matter as the mere stuff of control’: making their way in the world, conceived as a design problem.[168] But there is something about this progress that turns it blind. The geoengineers do not reflect on the direction and drift of society as a whole. They do not ask ‘the question of how to establish a form of society itself in which the possibility of such catastrophes’ as climate breakdown ‘would be excluded’: they merely look down at what they have on the desk in front of them.[169] Because a higher perspective is missing, rationality regresses to a constricted obsession with technology. Adorno speaks of an ‘infantile and

repressed behaviour' similar to 'that of the child, which cannot rest until the clock has been opened up and it can see how the little cogs work inside it'; and such micro-rationality is the only fare on offer when the question of the purpose of society has been taken off the table.[170] Worse still, it equips the central blindness with better instruments. If the king is both blind and mad, handing him sharper spears is not a service to humanity. An instrumental rationality in the employ of an irrational whole will arm it, so that every 'example of progress, in any concrete particular case, also immediately takes on a threatening and terrifying character'.[171] Probably for this reason, high-altitude turbofans and four-pylon nacelles do not sound particularly soothing.

A society that tries to manage every problem, every crisis with a fresh batch of technologies in the end becomes a hardened invasion force for the domination of nature. Marching over field after field, it reinforces existing property relations as relentlessly as it tries to subjugate one more residue of autonomous nature – or, as Keith himself argued in the article that made his name, from the year 2000: 'The drive to impose human rationality on the disorder of nature by technological means constitutes a central element of the modernist program.'[172] Geoengineering is not a negation but a continuation of fossil fuels and their logic by other means.[173] Both originate in 'the drive' – a recurring, revealing term – 'to manipulate nature to suit human ends'; when the first form creates a quandary, the second supervenes (and so on).[174] Never is the drive and its overlords called into question. And Keith – the Keith of 2000, but nothing indicates a conversion – has gladly volunteered as the knight for this creed. It's as if he read the collected works of Adorno and Marcuse during the moonlit wee hours of his college years and decided to dedicate his life to a live action role-playing game of critical theory. Geoengineering matches their nightmares only too well. The better it works, the worse it will be.

The unbearable lightness of a screen

If geoengineering comes across as an exercise in extremism, there is also something exceedingly familiar and ordinary about it: this tech would dovetail perfectly with the ways of the world. Treating crisis at the level of

symptom, propping up domination by force, refusing to abide by limits, advancing instrumental rationality even further – all is part of the routine protocol. But perhaps most banal is technology as such. Climate politics in the overshoot conjuncture has come to revolve ever more closely around technologies of every imaginable kind; and in this respect, it partakes of a wider malaise. Life in overlate capitalism is glutted with devices for smoothing out each wrinkle and easing every path. Digital devices, of course, are in a class of their own: but geoengineering has a deep affinity with them. A welter of research has shown how they produce much the same syndromes.

Digital technology is 'a flight from the real', write Richard Frankel and Victor J. Krebs in *Human Virtuality and Digital Life: Philosophical and Psychoanalytical Perspectives*, the most devastatingly powerful critique of it so far written.[175] 'As more and more of our life is enchained to the circuits and devices that constitute the everyday digital, there is a turning away from the world.'[176] This insight has lost none of its urgency for now being common knowledge.[177] It denotes the ostensible paradox that the more practical problems are solved by the marvels of modern tech, the more devices mediate between subject and world, the more the latter is screened out. A reality that appears to be mastered by instruments is no longer experienced; it recedes from view.[178] In its place stands the empty I. Digital technology serves him as His Majesty of the universe: 'in virtual reality, the ego has near total jurisdiction over how things happen'.[179] Here is an apparatus for narcissism such as the world has never seen. It activates 'insatiable cravings to have reality conform to our wishes, seducing us into the hubris inherent to technological power'.[180] Everything is obsessively quantified and measured and computed, everything compulsively served up for consumption; limits do not enter the picture framed by the screen.[181] 'We expect the world to behave like the digital, where there are no limits to what we can have' – the very definition, again, of irrationality.[182]

Digital technology is thus a machine for the production and universalisation of psychic disorders: and geoengineering would be connected to it.[183] It would have a similar diagnostic profile. It would be to the smartphone what the cathedral was to the crucifix. It would be but a bigger exercise in putting up a screen, literally. And geoengineering too would be fully at one with the drive.

How blindness came to rule

What of that drive? It propels the capitalist, along lines first sketched by Marx in the chapter on the working day. His account opens with the observation that reality exhibits certain physical limits, boundaries that inhere in the diurnal cycle and the needs of a body; within the twenty-four hours of 'the natural day', there are only so many a human being can possibly expend on labour. But capital has no regard for such limits. It refuses to see them. This is because it has 'one sole driving force, the drive to valorise itself', a point repeated throughout the chapter: here is 'a blind and measureless drive', a 'blind desire for profit' that cannot, by its own reason, stop before external barriers, which do not even come into sight.[184]

In the finest work of Freudo-Marxist theory to appear in at least a generation, *Infinite Greed: The Inhuman Selfishness of Capital*, Adrian Johnston demonstrates how Marx developed a theory of the drive before Freud.[185] The word for 'drive' in the German original is *Trieb*. When Marx writes of the 'driving force' of capital, he uses the term *Lebenstrieb*, a Freudian synonym for Eros. Elsewhere in the first volume, he refers to the drive of enrichment (*Beriechtungstrieb*), the drive of accumulation (*Akkumulationstrieb*), the drive of self-valorisation (*Selbstverwertungstrieb*).[186] But it is in the analysis of the working day that the logic is most sharply in focus. While Marx here varies his portrait of the capitalist with phrases like 'insatiable appetite' and 'werewolf-like hunger', drive is the central category and propulsive force of the mechanisms laid out in the chapter: above all, the tendency to push the worker beyond the limits of endurance, into twelve or fourteen or even more hours of labour per day.[187] She becomes 'an absolutely exhausted organism', on the brink of death.[188] To illustrate the surreally detached mentality, Marx famously borrows the French expression *après moi, le déluge*, which has renewed resonance in the age of climate breakdown; and just before these words, he comments on the bourgeois attitude to extinction. Capital is guilty of 'denying the sufferings of the legions of workers surrounding it' – bourgeois coldness, or a primitive accumulation of denial – as perturbed by 'the sight of the coming degradation and final depopulation of the human race, as by the probable fall of the earth into the sun'.[189] Capital, in short, does not care. Capital 'asks no questions' about the misery it creates. Most

significantly, it is here that Marx draws his parallels between the exploitation of the worker and that of the soil: capital abuses both with the same indifference to their respective limits.[190]

This refusal to accept limits is the quintessence of capital, like soaring flight for an eagle; it is its quasi-species-like being. ‘As representative of the general form of wealth – money – capital is the endless and limitless drive’ – the *Trieb* again – ‘to go beyond its limiting barrier. Every boundary is and has to be a barrier for it,’ something to glide over in disdain.[191] In an exegesis of unusual vigour, Johnston renews the fundamental Marxian insight into why this should be so. ‘One can always have more money.’[192] Because money is a measure of quantity, it rolls on and on; and once it has taken hold of the biophysical resources of the world through the production of commodities, it draws every living thing into this mother of all avalanches, which cannot, by itself, ever come to a rest: the *Trieb* is nothing but M-C-M’.[193] If capital were to become ‘comfortable’ within a limit, it would have ‘declined from exchange value to use value, from the general form of wealth to a specific, substantial mode of the same’ (Marx).[194] The overshoot conjuncture is thus present already in the concept of capital. So is overshoot ideology and the attendant features, all flowing from ‘a central antinomy of bourgeois society. To preserve itself, to remain the same, to “be”, that society too must constantly expand, progress, advance its frontiers, not respect any limit, not remain the same,’ in the words of Adorno – ‘not respect any limit’: neither 1.5°C nor 2°C, because it would check the production of exchange-value from fossil fuels – ‘advance its frontiers’: into the stratosphere and the more than three dimensions of late value form. Bourgeois society ‘would no sooner reach a ceiling’ than ‘its own concept would force its self-liquidation’.[195] And this has consequences in the clinical department of psychiatry.

It first appears as a matter of pain and pleasure. Faced with an outcry over the degradation of life, capital responds, as rendered by Marx: ‘Should that pain trouble us, since it increases our pleasure (profit)?’[196] Again, the term for pleasure, *Lust*, is the same used by Freud. The proto-psychoanalytic nomenclature is consistently striking. Translated fully, it seems to suggest that capital has no other agent in its psychic apparatus than an id.[197] Capital knows no reality principle. It is possessed only by a pleasure principle, although the *Lust* is of a strangely abstract and

disembodied kind; for the point is never that the capitalist himself shall wallow in the consumption of his own goods, as though in an orgy.[198] Nor does the defect sit at the level of character. It is a truism of Marxian theory that the behavioural predispositions do not come from the individual capitalist, who, in his private life, need not be any kind of psychopath. He can be a mature family man (or the rare woman) with years of healing therapy behind him (her). When Darren Woods promised to 'deliver exceptional value' or Vicky Hollub to go after the last barrel of oil, their heartfelt desires were immaterial to the urge: they were obligated to vent it, or else their corporations would be outcompeted and cease to be parts of capital. Their professional souls were 'the soul of capital' – an impersonal soul, structural, implacable.[199] M-C-M' exhibits the peculiar features of 'limitlessness' and 'infinitude' on the one hand; on the other, 'headlessness' and 'automaticity'.[200] It is 'a drive without a driver'.[201]

If this drive knows no limits and no subjective character traits, in what relation does it stand to human instincts as such, those identified by psychoanalysts as constants across the ages? Johnston here follows the lead from Fenichel and his extraordinary essay 'The Drive to Amass Wealth'.[202] Children always seem to enjoy collecting things like stones. They search for cherished objects, hoard them, turn them into their exclusive possessions; at a certain age, they are also fascinated by their own faeces. From such interests, Sándor Ferenczi, a close confidante of Freud, deduced the instinctual source for accumulation. Money is the natural solution to a drive that seized on sticks or pearls or turds at an earlier stage of development. Against this view, Fenichel adduces the Marxian postulate: the capitalist *has no choice* but to amass wealth, since if he fails in this regard, he is done for. The sole drive required to explain such amassment is self-preservation. A card-carrying Freudo-Marxist, Fenichel rejects recourse to timeless, pseudo-biological factors when trying to explain novelties in history: capitalism has not developed as 'the result of an "anal-erotic mutation" that has fallen from heaven'.[203] Something as eccentric and epochal as this mode of production cannot be attributed to children's fondness for their faeces. (Indeed, as we have seen, the faecal character of capitalism itself has a historical temporality.)

But this is not the end of the story, for 'a social system of this kind *makes use of* and strengthens erogenous drives that serve the necessity for

accumulating'.[204] The most successful capitalist is the one who does personify the ruthlessness and dispenses with all compunctions and makes the outer drive his innermost wish. If he can put a desire for maximum power and self-regard in the service of value, there will be more of it. Best for his results is to cordon off into some small corner of his nonprofessional life any impulses to acknowledge other people and organisms and their needs. Turning Ferenczi inside out, Fenichel argues that capitalist property relations demand and give direction to sordid motives; much like tennis exercises certain muscles in the arm, they call forth the lust they need.[205] Playing by the rules of the competitive game does not leave the soul unaffected. The meta-soul of capital rather takes up residence in the bourgeois interior, most directly in those who behave as capitalists in the public arena of production. David Pavón-Cuéllar puts it vividly: 'Brains, neurons and nervous fibres are required by capital for it to acquire its characteristic ambitious and ruthless psyche. However, once acquired, this is no longer the psyche of people who possess capital, but of capital that possesses, like a demon, the people who have sold their souls to it.'[206] Those people will tend to lose their reality principle. They will undergo a 'slackening of the relation to the external world', filled as it is with limits.[207] Capitalist society is psychopathological as a whole; and the pathologies take hold of real people, who become unable to recognise what stands in the way for their own drive.[208] Hence late (climate) politics assumes the character of one long walk through a mental asylum – a ward without treatment, just warehousing and acting-out.

This is not to say that the limits of reality have never breached the psychic defence mechanisms of the bourgeoisie, of course. The original struggle over the working day is one case among many. Marx's story of it memorably ends on a positive note. The workers of Britain rose up against overexploitation and, after decades of organising, petitioning, marching, striking and threatening revolution, managed to put a limit on it. The Ten Hours Act of 1847 was the fruit of resistance. Because of the pressure from organised labour, the state had to step into the fray and bridle capital – left to its own devices, endlessly ravenous for working hours – and impose on it a minimal sense of where reality began.[209] Capital 'takes no account of the health and the length of life of the worker, unless society forces it to do so'.[210] We can then posit that *resistance from below is the source of the*

reality principle in capitalist society, and, where such resistance is missing, there is only the blind drive ('resistance' here not in the Freudian but in the strictly political sense). As for the working day, its extension in early capitalist development triggered resistance 'as soon as the working class, stunned at first by the noise and turmoil of the new system of production, had recovered its senses'.[211] Because the abused bodies had minds of their own, the transgression provoked a counterforce. There is, in *Capital*, a one-to-one correspondence between the extension of the working day and the formation of the working class as a class for itself. As for planetary boundaries, however, matters are not that straightforward.

The breach of a tolerable temperature limit or CO_2 concentration does not elicit the same spontaneous fightback. Elements of the climate system do not possess the faculty of agency. If workers are pushed into a state of criticality, they will react in some manner – not necessarily, but possibly, through political organising – but an ice sheet that suffers the same fate, or a tundra or a forest, cannot turn on the capitalists that overburden them. If climate breakdown ever spurs resistance, it will come from people who suffer its consequences or otherwise take up the cause in the second or third or fourth step. A counterforce can be formed only through qualitatively different mediations. The historical task the climate movement set itself – most clearly in the years 2018–20 – was to fill the yawning hole where the ten-hour movement once confronted the same demonic drive; but it succeeded in wringing at most 'purely nominal' concessions from states, barely advancing further than the factory legislation of, say, 1802.[212] It has yet to develop anything like the striking force of the early proletariat. The chapter on the working day can thereby be read as a negative foil for the irrationality currently running rampant.[213] Because climate limits are not embodied in a class, breaking them does not call forth the same response as the breaking down of workers' bodies did in Marx's discussion in this chapter and beyond. The formation of a subject of resistance is here a far more circuitous, drawn-out, uncertain affair.

It follows that capitalist society, in the age of the climate crisis, is *more thoroughly and uninhibitedly irrational* than in the classical era of the struggle between labour and capital: the source of the reality principle – from below, outside of capital – is orders of magnitude weaker. But this disappearance of a medium for reminding capital of reality is also, of

course, a result of the political decomposition of the working class itself. The historical antagonist of capital is no longer strong enough to force it to come to its senses.[214] Up until the defeat of the class across the globe in the 1980s, there could still be something like enlightened liberalism, bourgeois states vulnerable to the power of labour and hence capable of discerning at least a few realities. (Indeed, as late as the early 1980s, the prospect of nuclear winter contributed to disarmament efforts – in comparison with the present, a marvel of reason. The Montreal Protocol is another case in point.) But with the triumph of neoliberalism, in keeping with Weintrobe's chronology, the world was flung into the universe precociously explored by critical theory: one where the slide into catastrophe appears inexorable, since there are (as yet) no oppositional forces capable of blocking it.

The whole is now unrestrainedly irrational. Little cogs and turbofans might work perfectly, but the totality of which they are part has become rudderless in the extreme. This is not, as Adorno never tired of pointing out, because class antagonism has disappeared; to the contrary, it is as alive and determinant as ever – only one side is crushingly victorious. The profit motive has been set free to rule alone, and it tears the world apart.[215] Or, in the condensed-but-elaborate syntax of *Negative Dialectics*: 'Society stays alive, not despite its antagonism, but by means of it; the profit interest and thus the class relationship make up the objective motor of the production process which the life of all men hangs by, and the primacy of which has its vanishing point *in the death of all*.'[216]

One tragedy of the climate crisis is that its outbreak in the 1980s and '90s coincided with the defeat of the working class *and* failed to spur any class-based or other system-wide resistance. Whether the latter might happen in deeper, more desperate phases of the overshoot conjuncture remains an open question. So far, it evidently has not. The irrationality of the whole stands in direct proportion to this double absence – of a subject of resistance defending the limits of the climate system, like the English workers defended their own bodies; of working-class politics itself, enfeebled beyond historical recognition. At the centre is only the void of the drive. And it is precisely on this giant drifting vessel that geoengineering – and so much else of late climate politics – piggybacks.

Reason is refusal

The *Akkumulationstrieb* is limitless and headless but not timeless: it has developed out of capitalist property relations, as they wrested control over human metabolism over the course of the past centuries. The forces of climate destruction are among its products. In the spirit of the second generation, we should resist more or less flippant attempts to explain the breakdown with transhistorical complexes or drives – notably, the hypothesis that the present generation is bent on destroying the earth in a murderous act of sibling rivalry with future generations, which would thereby be denied a liveable planet, or the idea that humans fill the atmosphere with emissions because as infants they become used to their mothers taking away waste products.[217] Likewise regarding the technologies for treating the symptoms of global warming: these cannot possibly have arisen as a result of phenomena always and everywhere present in the psyche. Fenichel offers the following synoptic formulations for a conjunctural Freudo-Marxist theory of technology:

> Let us think of an invention with a practical and at the same time a sexual symbolic value, for example, a Zeppelin airship which is certainly a sexual symbol but on which people can also fly. In order to understand inventions we must not overlook the *rational necessity* which must be present before an invention can result, and which arises *only in a certain social situation*. The task which is imposed in reality, can evidently be completed with the help of instinctual drives … [indeed, it can] only be performed with the aid of a certain instinctual structure.[218]

Substitute the sulphate planes for the Zeppelins, and we get the following: an invention of such a kind can only come about in a highly determinate situation. A ‘rational necessity’ – the control emergency – puts the novel productive force in orbit. But the task is completed with the help of instinctual drives, possibly culminating in the quasi-sexual fetishisation of the plane, certainly beginning with the lust for profit. Moreover, the emergency is the result of the previous work of that same lust as it clashes with biophysical reality. Geoengineering would give it extended reign. We then get precisely the recursive spiral Fenichel seeks to outline. ‘Not only do social influences alter the instinctual structure, but the thus modified instinctual structure reacts again upon social reality through the actions of individuals.’[219] In schematic terms: capitalist property relations elevate the drive to amass wealth into the engine of the social order; when this drive

collides with the climate system, denial is the paramount response; in the moment of emergency, means of repression are rolled out; they have a haunting psychopathology in them.

As we write this, in the middle of the 2020s, this schema remains theoretical. The hard reality of a geoengineered planet is still in the future. One must hope that it never comes to pass. If it never does, however, geoengineering nonetheless reveals something about the psychic make-up of the – white, male – bourgeois subject in the early twenty-first century. Oddly, it represents a *fantasy* of repression, a yearning for the impacts of climate breakdown to be undone by technical means.[220] We here have the opportunity to study psychic processes feeding into a technology *in statu nascendi*. Considered from this angle, geoengineering, if only as a scientific template, issues from and partakes in 'the psychic state of deep cultural anxiety about the future for the planet and for humans', in the words of E. Ann Kaplan – or, of Adorno, 'the dizziness that overcomes a society threatened by total destruction'.[221] There really seems to be a ghost in the machine this time.

If this is a valid perspective, it comes with the irony that geoengineering is normally defined as the *conscious* or deliberate manipulation of the climate system; we are suggesting that it has unconscious dimensions of moment.[222] And if we accept the insight that the progression of the climate crisis is constituted by denial, psychology really ought to have an authoritative position in this field. 'The realm specific to psychology is the realm of irrationality,' and the climate crisis is a journey ever deeper into that realm, even if the rationalist-optimists take the helm: for precisely their rationalism is irrational.[223] Insofar as reality is determined by irrational forces, positing a rational world means departing from that reality – while thereby also sinking headlong, without resistance, into it. Truly rational research on geoengineering would zoom in on the irrational.[224] 'Truly rational behaviour', in this era as in Marcuse's, would mean 'the refusal to go along, and the effort to do away with the conditions which produce the insanity'.[225]

18

Empire of the Stratosphere

Some posit that geoengineering could bring the world together. The family of nations would unite in taming the climate monster: a shared mission, a collective effort to save the planet in the last moment.[1] Geoengineering might then have ‘tremendous potential for security and peace’ – a possibility unduly ignored by its critics.[2] It could curtail the climate impacts most likely to induce conflict, notably migration; under the circling planes, the masses of the South would be able to stay put.[3] It could pre-empt violent obstruction of the transition away from fossil fuels by letting their producers remain in business a while longer – geoengineering as an ‘appeasement of fossil fuel producing regimes’ (or capital protection as peace for our time.) It could even foster a spirit of fraternity among the states ‘building a collective to manage solar radiation’ and using the stratosphere as a global commons, perhaps with a little help from UNEP or the World Meteorological Organization.[4] How likely is this scenario?

It threatens to come apart already in the moment of the control emergency. With geoengineering as a break on the heating, the world is imagined as pulling its handle in unison. But one cannot take for granted that the emergency will be perceived from one single vantage point. The climate apocalypse is bound to proceed along patterns uneven and combined, the force of avalanches distributed unequally: Brazil might want to pull the brake early in an attempt to ward off a tipping point in the Amazon, while China might prefer to wait.[5] A declaration of planetary emergency may well be unilateral. Once deployment gets underway, conflicts of interest are sure to arise, because it would, as we have seen, operate as a giant scrambler of regional climates. It will not redound to the

equal benefit of all. From this point onwards, it is rather easier to imagine discord than harmony: nations will develop divergent preferences.[6] Their experiences in the new world will be – or will be perceived to be – a function of the operational details of the injections, their latitude, altitude, durations, amounts, parameters, all open for contestation.

Iran might ask for adjustments to return its rain. Indonesia could tug in the opposite direction. Should temperatures be cut with one whole degree, or two, or just a few tenths, so as to not close down the lucrative new frontiers of the Arctic? Like all other forms of overshoot politics – including, as we have seen, return through removal – geoengineering would be prone to set off rounds of claims and counterclaims. But the latter would, arguably, have the greatest potential for acrimony, because it comes with the promise of improvement: if climates can be engineered, they can also be (expected to become) *better* than before. ('It's just not true that the climate we have is automatically the best one,' said Keith.[7]) Every nation might seek a design optimal to itself. Hopes for higher dividends and resentment against winners could usher in an era of climate – or perhaps post-climate – nationalism.[8] Given the designer logic and the side effects and unevenness inherent in the technology, a pitting of some nations against others seems all but inevitable.

Rationalist-optimists have recognised this potential and come up with solutions for it. Conflicts could be avoided by a compensation mechanism: if one country suffers loss and damage, others will pay indemnities.[9] 'Some sort of international fund to share this burden seems logical.'[10] Oh, does it seem logical. Once again, geoengineering is here placed in a universe parallel to that of the climate crisis, where negotiations over loss and damage have proved singularly unsuccessful from the standpoint of the aggrieved and funds for sharing the burden have remained glaringly empty chests.[11] 'One rational approach might be to coordinate any efforts' to intervene into the stratosphere 'at the highest level possible. Ideally that might mean the UN General Assembly,' writes Wagner, 'ideally' again being the signifier that carries meaning.[12] The basic antinomy returns at the level of governance: a cacophony of preferences is unlikely to be graciously managed by the same 'world community' that failed to prevent dangerous anthropogenic interference with the climate system, any number of annual summits notwithstanding. Nor will a torrent of research on geoengineering

calm emotions, as some have suggested. In ignorance there is at least the pretension of innocence. With increased certainty of side effects comes the possibility of deliberately messing up the climate of some rival country (or of being suspected of doing so). Whatever way geoengineering is turned, friction and fracas look set to continue beyond the emergency: ‘Verily, there are no greater Utopists in existence than these Bourgeois optimists,’ as Karl Marx wrote in another context.[13]

And if conflict is a more realistic prognosis than peace under the parasol, there is also an expected winner. In a dispute between an actor who prefers a lot and one who wants less stratospheric aerosol injection, the upper hand will be with the former. The state with the desire and capability to loft the greatest quantity of soot into the air carries the day.[14] Geoengineering lends itself to ‘over-provisioning’; or, in game-theoretical terms, it exhibits the problem of the free driver. The more classical problem is that of the free rider: if all agents benefit from the reduction of something like pollution, one agent might choose to gain from the efforts of everyone else and keep polluting; and if this free rider is copied by others, the whole exercise dissolves.[15] In geoengineering, to the contrary, the outcome is determined by the free *driver*: it is enough that *one* single state gets going for the whole thing to happen, even if others do not want it to.[16] This structure, this inherent momentum towards the maximum, is as damaging for notions of peaceful consensus as for those of moderation and modesty. But it is remarkably consonant with the boundlessness of the drive of capital.

If some countries become upset with the free driver, how might they react? One should not count on them passively accepting their fate. In extremis, those who want to reduce injection rates could resort to shooting down planes.[17] Lower-level types of retaliatory action might include sabotage; with a globe-spanning infrastructure for soot delivery, there will be no shortage of targets for this tactic.[18] Or dissenters could engage in ‘counter-geoengineering’: deliberately releasing ultra-potent greenhouse gases, chemicals with exotic names such as sulphur hexafluoride and difluoromethane, to overtop the sulphate and reheat the planet, perhaps to get a monsoon back. Or they could just burn more coal for the sake of it. India sits on a lot of this fuel. An arms race may ensue. ‘Cloud wars’ between geoengineers and counter-geoengineers could rage above and on the ground – the coal furnaces of India bombed by fighter jets, the saboteurs

hunted across borders.[19] Rationalist-optimist attempts to discredit such scenarios descend into the usual ultra-charitable interpretations of the world: states with countervailing stockpiles will use them no more than those with weapons of mass destruction; the mere threat will contribute to peace and understanding; no one would ever do something so destructive.[20] (That is, no one would ever release great quantities of greenhouse gases.)

Only one insurance against counter-geoengineering does carry some weight: the capabilities to tinker with the climate will have to 'be limited to major powers or coalitions'.[21] Not everyone can be allowed to engineer the planet according to taste. Put differently, the geoengineer-in-chief will need to establish *a monopoly on stratospheric violence*. The only way to avoid a sky war for climate control would be for one central actor to impose its will on everyone else (and, presumably, this actor would have the same identity as the free rider). In the end, it is either counter-geoengineering and *bellum omnium contra omnes* or a full-spectrum-dominant, maximising Leviathan.[22] The technology would then have both a Freudian and a Hobbesian logic: the repression of global heating executed through a repressive apparatus reining in the tendency to atmospheric anarchy. Force must decide.[23]

For all their professed allegiance to enlightenment values, rationalist-optimists tend to embrace this logic. 'Geoengineering seems to demand centralised control,' Keith blithely accepts.[24] Participation will need to be restricted. Not everyone can be allowed a say in these matters, like Keith's own ethics of experimentation suggest. After deployment, decisions about how to proceed – how to assess info, modulate feedback, update tech – would have to 'rely on expert analysis' and 'be institutionally insulated from broader debates'. In short, 'some degree of technocracy will be necessary.'[25] But if the rationalist-optimists call forth the spectre of tyranny, they have to swiftly bury it: technocratic geoengineering is not, we are also told, incompatible with democracy – for do not central banks regulate the economy shielded from popular oversight?[26] And is not democracy everywhere circumscribed?[27] And is it not always the case that 'wealth and power shape individuals' control over their own lives and their access to decision-making'?[28] Here, at last, the rationalist-optimists explicitly align with the squalid realities of late capitalist society, of which their geoengineered world would be an intensification – a leap further into

authoritarian politics, now on the scale of planetary management. Some must establish their stratospheric rule over others.[29]

The name of the Leviathan

Who would it be? Who could be the first mover and free driver? In one of his peer-reviewed articles, Andrew Lockley of SATAN toyed with the idea of a 'billionaires' club' consisting of figures like Musk, Gates, Bezos, Mark Zuckerberg and Warren Buffett. An advantage of a such a broad club would be 'reduced dependency on any one individual – who is inevitably vulnerable to personal crises, bankruptcy, frailty, death, or mental and physical illness'. A billionaires' club would have mental health and 'might approach legitimacy' and provide the 'stability' required for the operation; but Lockley of SATAN could also imagine the fans of Taylor Swift or Manchester United, the Catholic Church or Marvel Comics rising to the occasion with much of humanity behind it.[30] Let us give the earth to the Swifties – we can safely file this under the rubric of late capitalist delirium. None of these candidates has much chance of success. Not only would the financial and logistical challenges require the involvement of a major economy, as we have seen; state apparatuses would hardly sit idle if others move. In a control emergency, some state would likely step in as a committee for managing the climatic affairs of at least one whole bourgeoisie.

What state? The People's Republic of China has tried its hand at rainfall manipulation for more than half a century. It has experience with large-scale engineering projects, an efficient top-down command structure, much to lose from accelerating climate breakdown, much to lose from serious mitigation too.[31] The Chinese state might have good reason to take the initiative. So, of course, might the European Union, or Russia, or even India, these being among the major economies that could do the job. But the prime candidate remains the US.[32] Far ahead of everyone else, it is where the vast bulk of research is conducted and home to the requisite platforms and – technological, logistical, economic – capacities. It was hardly a coincidence that Make Sunsets was an American company and not Spanish or Somali. Were the US to initiate geoengineering, the switch from denial to

repression would be consummate: for about half of the time since the signing of the UNFCCC in 1992, this country has been governed by literal climate denialists; for the other half, by implicatory ditto. Throughout the period, no other state has done more to obstruct mitigation.[33] All the more logical that it would also fire this gun first.

But surely the main reason for the top spot going to the US is the power of its armed forces. With 750 bases strung across the planet, a greater military budget than the fourteen next contenders combined, technology at the cutting edge of every branch of warfare, the largest stockpile of nuclear bombs and, not the least important, global air supremacy, the US remains, as of the mid-2020s, the empire *ne plus ultra*.[34] Now try to imagine that some other state declares its intention to launch the planes. Imagine it is China or Russia, a state not allied to the US but locked in a rivalry with it. If the upstart were to succeed, it would grab the reins of planetary governance: the power to set average temperature on Earth and flood or torch any of its regions. If planes from Beijing get going and the side effects become severe for the American Midwest or some other zone of interest to Washington, nothing would guarantee that the former would abide by polite requests for adjustment. There might as well be laughter from Tiananmen Square: China could take the lead precisely to end the dominance of the US and effect a stratospheric *coup d'état*.[35]

But for this same reason, it defies all belief that the US would acquiesce to China – or indeed any other state that is not a very trustworthy ally – moving first. From the moment an intention is declared (or discovered by intelligence), it would take months or years (possibly many) before payloads are delivered.[36] The US would have time to catch up and take over (or deny the rival the privilege in some other way). Anything else would be tantamount to abdication of the imperial throne. If the US continues to exist in current form, under any configurations of geopolitical power conceivable from the present, it will insist on having the first and the last word.[37] And, indeed, in late 2024 it was revealed that federal agencies had established a worldwide network of sentries – from the coasts of Africa to Antarctica – from which they launched surveillance balloons able to detect even small releases of aerosols. The eye of the Leviathan was already scanning the globe.[38]

The Pentagon has long studied climate change through the lens of ‘national security’: it knows that maps will be redrawn and terrains begin to slide in unpredictable directions; for the rest of the century, the projection of American power will have to pass through higher degrees of heat.[39] The same *ipso facto* applies to a geoengineered world. The Pentagon would then hardly appreciate initiatives from the united fans of Taylor Swift or any other entity with whimsical or even just slightly unreliable conceptions of national security. But some entities not identical with the US might offer valued assistance. The prime candidate would be the state of Israel.

It was scarcely a coincidence that Stardust Solutions was an Israeli company and not Palestinian or Pakistani. The ‘security technology ecosystem’ it boasted of was, in some respects, unique in the world: a symbiosis between a flora of high-tech startups and the top predator of the IDF, not quite matched even in the US.[40] The armed forces here served as an exceptionally generative incubator of new tech. The rest of the West had long imported that tech into its arsenal for combatting various symptoms: Israeli drones for patrolling the borders of the US and the EU, Israeli knowledge about wall construction, Israeli surveillance services for tracking the spread of Covid-19; facial recognition, digital spyware, policing tactics to subdue various enemies and guard facilities like airports and nuclear plants.[41] Since 1948, this entity has accumulated outstanding expertise in technology for washing away symptoms of a cause it cannot, by its very nature, ever address, viz. the colonisation of Palestine. The impulsion and every manner of fuel to that colonisation always came from the western core of empire; and after 7 October, traffic on the old airbridge reached its highest flow ever.[42] To mention just one case, the occupation became dependent on the services of Microsoft. Azure – the very same cloud computing platform sold to oil and gas companies – and other systems from the US tech giant were instrumental to the destruction of Gaza.[43] But the traffic was two-way. Because of the place of the occupation in the constellation of imperial power – its status as outpost, or ‘satellite campus’ – it served the top tiers of digital and military technology in the West with the latest solutions straight from the frontlines. After 7 October, this liaison, between a militarising Silicon Valley and a flourishing startup nation, attained a higher fervour.[44]

It is in this context that the Stardust episode must be seen. It signified a renewal of the ‘Palestine laboratory’ as a place for testing ‘the most precise and successful methods of domination’.[45] In his revelatory *The Palestine Laboratory: How Israel Exports the Technology of Occupation around the World*, Antony Loewenstein briefly speculates on how climate breakdown will provide further stimulus to the import–export relation when ‘nation-states do not respond with active measures to reduce the impacts of surging temperatures’ – that is, fail to mitigate – ‘but instead ghettoise themselves, Israeli-style’ and buy the latest tech from the armed outpost to fortify their own enclaves of affluence.[46] This would be muscular adaptationism and perhaps fossil fascism with a Zionist accent. Could the Pentagon also give Israel the go-ahead to deploy the sulphate planes? Perhaps not so likely. Given the reputation of the now genocidal entity, it would risk inflaming too many passions, first of all in the immediate vicinity. One could imagine what Iran would say if its precipitation dipped (or was only perceived to have dipped) under an awning of Israeli soot.[47] More likely is a contribution from the Palestine laboratory *up to the moment of deployment*, reserved by the US for itself. The dominant state will seek control through the greatest possible stability. This Leviathan might wield a sword made in Israel, but head and hands of the executioner will be American.

The ascension of America

If the US is the greatest empire the world has ever seen, it is also the epitome of a fossil empire, in at least three respects. First, since the late nineteenth century, but particularly since 1945, it has exercised power, including a superior capacity to kill people, in the service of fossil capital, guarding and deepening and elongating its circuits of accumulation on a world scale.[48] Second, it is itself the stronghold of primitive fossil capital. Reclaiming the position as the top producer of oil and gas in the early twenty-first century, it contains the largest concentration of value expanding directly through the extraction.[49] The US has taken under its worldwide wings the classes doing business through fossil fuels; and its own backbone is crude. It follows that capital destruction would clash with the job assignment of this state apparatus on two scales, the global and the national:

it would threaten the worst kind of danger to business, against which the US has always kept the world safe; and it would be a threat to American capital most specifically. But the two scales are blurred, of course, as befits an empire. The boom in Iraqi oil production set off by the US invasion was a boon to ExxonMobil, to take but one example.[50] This empire is fossil on the frontiers *and* at home. A geoengineering operation run by the US would thus be drawn towards substitution with the greatest force: no other nation has so much capital to protect by sending up the sulphate planes.[51] Their sorties would be less a novelty than a classical American mission.

But there is also a third, often overlooked, aspect of the fossil nature of this empire: its raw military muscle mass is built with fossil fuels. The Pentagon is the single largest institutional consumer in the world.[52] In her illuminating *The Pentagon, Climate Change, and War*, Neta Crawford charts the history of this construction through what she calls 'the deep cycle': once the armed forces of the US realised the operational value of first coal and then oil, securing access to supplies became a strategic priority; with the fuels in safe hands, their utilisation spread throughout the economy; military use inspired private use; the centrality of this type of energy to the US social formation became ever more accentuated; the mandate for the armed forces to safeguard them was then redoubled and so on.[53] The Middle East was and still is the main theatre for this cycle. A non-negligible share of the oil extracted from that region would enter the fuel tanks of the US war machine; around the time of the Iraq invasion, ExxonMobil, ADNOC and the Kuwait Petroleum Corporation were among its top suppliers. A network of trucks, pipelines, rails, barges, tankers conveyed the oil to bases in the four corners of the world.[54] And no part of the machine would receive it with greater existential urgency than the air force. After Vietnam, the US became wont to project its power by bombing targets from the air rather than sending ground troops in: and this exercise rested entirely on jet fuel for maximum speed and range, by far the largest share of fossil fuel consumption in the US military.[55] High-flying fighter jets already play a role in the warming hell.

It goes without saying, then, that the idea of ending fossil fuels does not sit well with the generals. From Kyoto to Paris, they have kept their own emissions outside the purview of international climate politics, as a classified matter of national security. Any impingement on the use of jet

fuel in particular would reduce ‘freedom’ of and ‘readiness’ for combat.[56] The potential of biofuel as an alternative is highly uncertain, and so far the Pentagon has spurned it; in the global geography of the fossil economy, there might be no sector whose emissions are harder to abate.[57] Few would be so instantly disempowered by a fossil fuel ban. Here the stranded assets would be of more than economic interest, the capital destruction translating into a liquidation of a major section of the armoury, the muscles of the US withering in a moment. If there is a hard core of maximum recalcitrance against a transition, the Pentagon in general and its air force in particular might be it. What, then, would it mean to have them managing a geoengineering operation? Were the sulphate planes to be incorporated into the fleet of the US Air Force, they might be expected to protect their next-of-kin and the rest of the armed forces: the geoengineer would be the agent with the strongest incentive to stay with fossil fuels.

Such incorporation seems all but foreordained. When Smith consulted companies for the design of planes, he sat down with Northrup Grumman, Lockheed Martin, Boeing and other suppliers of American aerial supremacy.[58] Precisely the unrivalled position of the US Air Force would make them the natural partner in any stratospheric aerosol injection conducted with planes (as opposed to, say, party balloons).[59] Some rationalist-optimists did not shy away from the association. ‘Militaries possess useful equipment and knowledge regarding complex logistical operations at high altitudes,’ Reynolds justified their likely involvement, and he hardly had the air forces of North Korea or Venezuela in mind.[60] Militarisation and Americanisation seem to be the combined fate of geoengineering. The reasons are several: once underway, the operation would have to be vigilantly guarded against any malefactors; protections would have to cover the whole supply chain from sulphate mines to engine factories and further to runways and aerial routes.[61] This would be ‘critical national infrastructure’ stretching across the globe, sheathed in imperial power. A military staying within its national borders would by definition be deficient. Who else than the Pentagon could run such a mission? By dint of its very constitution, the technology seems predestined to end up with the Leviathan already best positioned to govern earth and sky alike, rather as the latest innovation in surveillance systems will be passed on to the police and not the pushers on the block. Planes of a kind flock together.

Should something like this happen, it would upgrade the power of the US and its military through a leap without precedent. Full-spectrum dominance would come to include the climate of this planet. After ascension, the empire would hardly waste the opportunities to convert its atmospheric power into yields on the ground: the signing of more favourable trade agreements, the establishment of more bases, incursions deeper into coveted territories.[62] It has been suggested that the termination shock itself would be the ultimate bargaining chip.[63] The US would threaten an adversary with letting the sword of Damocles fall on its neck; but here one could, for once, raise a convincing rationalist-optimist objection. Its trajectory would have no selective precision. It would be more like a guillotine over humanity or the Mutually Assured Destruction of nuclear war. The US (or anyone else) is unlikely to blackmail others with a credible threat of termination, since it would be plainly suicidal.[64] But it is equally hard to picture an empire in the stratosphere *not* exploiting that source of power as against terrestrial rivals and rebels. If the geoengineer is in control of doses with side effects, its negotiating position in any dispute will be altogether superior.

From the vantage point of the mid-2020s, rekindled inter-imperialist rivalry looks set to be a feature of the next decades, perhaps the rest of the century. China and Russia challenge the American hegemon. Seemingly a throwback to earlier episodes of turmoil and successional strife, when Great Britain – the first fossil empire – faced a host of challengers, this phase would differ in more ways than one. Britain did not decline in a moment of climate breakdown.[65] Nor could it stage a comeback by bringing the climate under a semblance of control. For the first time, inter-imperialist rivalry would now be *articulated with a planetary crisis* in which the contenders can intervene by means of repression, the wielding of which would magically enhance their power over others. A harmonious cartel à la Kautsky's ultra-imperialism should not be expected. Conflict could be the rule rather than the exception long after deployment. Should American geoengineering hurt China badly, the People's Liberation Army could strike back, and so on; perhaps the imagination of cli-fi writers is the best resource for capturing such – still distant – scenarios. But the silhouette of what Kevin Surprise has called 'stratospheric imperialism' is already discernible.[66] The empire that wins the heavens will win the earth, to the detriment of more than its lateral rivals.

Could the planes migrate to the South?

In an imperial world, the main fault line still runs between North and South; and one feature of the geoengineering enterprise that strikes the eye is its exclusive origins in the former. The research has come out of the same northern institutions that would also ponder covering the South with tree farms. BECCS and the sulphate planes were here peas in a pod. To give just one example of how cavalier geoengineering research could be about the people of the South, one Northern team based a modelling exercise on the belief that the tropics currently suffer from a regional climate 'warmer-than-optimal'. Their temperatures are, by some objective standard, too high for affluence to evolve – whereas in the North they already hover 'around the optimum'. Southerners have so far been poorer than the Northerners because they have been warmer. As injections overcool the tropics, they would give a shot in the arm to GDP growth in the South and improve the chances of catching up with the North. Better yet, by flattening the gradient between tropics and poles, geoengineering would bring 'all countries' climates slightly closer'.[67] By this sleight of hand, one of the most disconcerting categories of side effects was transmuted into gifts of prosperity and egalitarianism to the South. What this study said was, in simpler terms, the following: you have been relatively poor because of comparative heat; but with our planes over your heads, your regional climates will approach ours and become unrecognisable to you and this will make you richer.

The darker nations were conspicuous by their absence from the 'geoclique' that fearlessly advanced this research frontier.[68] The fact that this clique purported to do its work in the interests of the wretched of the earth hardly made things better. One does not necessarily need the astringency of a Fanon to see through it. Some have argued that there is nothing intrinsically Northern about sulphate planes qua technology and that Southerners might as well appropriate them for their own purposes.[69] The same was often said about petroleum at the dawn of independence. But while oil could indeed be found in and exported from Nigeria and Algeria and Libya (with decidedly mixed effects on their populations), geoengineering is, as we have seen, by definition unsusceptible to diffusion. It cannot be duplicated like oil platforms: there has to be *one* actor doing it.

The case would then have to be made that the South could (and should) supply the requisite imperial force. And, indeed, in a world better than the present, it could perhaps be provided by a socialist federation of Africa or the Middle East on a war path with the old North – Fanonian geoengineering, under a balance of forces not yet seen on Earth. In the real world where this crisis rages out of control and the hangars are, for that same reason, opened, the technology rather leans towards some version of the white man's burden. Indeed, geoengineering might well be launched *under the pretext* of helping the Southern poor.[70]

Some groundwork in this direction was laid in the late 2010s by a project that sought to export intellectual investment in geoengineering to developing countries – or, to put them 'at the centre of the conversation'.[71] Known as the DEGREES initiative, it was funded by money from Richard Branson; Dustin Moskovitz, the cofounder of Facebook; another former Facebook executive; an heir to the Hyatt Hotels fortune; the IKEA Foundation and sundry other well-heeled givers, coming together to recruit scientists in the South to do research on solar radiation management.[72] Were the latter finally included as equal partners? Or was this the climatological equivalent of nursing intellectuals for comprador bourgeoisies? 'This just appears to be a way of trying to make Africa a test case for an unproven technology,' protested one Nigerian climate scientist, Chukwumerije Okereke, in an op-ed in the *New York Times* headlined 'My Continent Is Not Your Giant Climate Laboratory'.[73] He denounced geoengineering as 'a major distraction from the real change that we all know wealthier nations need to make' and called for a united African front to rule out experiments. Against such voices: the pooled wealth of northern billionaires trying to engage Southern hearts and minds.[74]

Their marginalisation was never due to an innate lack of interest. It was a result of the ways of the world, the deepest grooves of development that conditioned the research and will do the same to any deployment. A Leviathan arising from the South looks exceedingly improbable. Should it arise from the North – from the US, for instance – the peripheries of the world would be subordinated to a metropole in possession of the means of injection, with the power to calibrate them in its own best interests.[75] The springs of the Sahel would not be close to the Pentagon's heart.

Early in the overshoot conjuncture, an awareness of the dangers in store appeared to spread in the South. When the United Nations Environment Assembly deliberated on a Swiss resolution calling for the formation of a panel to study geoengineering, the core of the resistance was made up of the forty-seven countries in the African Group, flanked by Pakistan, Fiji, Vanuatu – all hypervulnerable to the heating; all stalwarts of mitigation since the dawn of climate diplomacy – as well as Colombia and Mexico (which, following the ordeal of Make Sunsets, demanded that outdoor experiments be condemned). Against them stood two nations that pushed for a permissive and rosy approach to the tech: the US and Saudi Arabia.[76] That alliance wore the logic of substitutionism on its sleeves. Geoengineering, it seemed, could only enter the material world through a passage of Northern power.

Climatic power grows out of the barrel of a gun (and vice versa)

> Control of space means control of the world, far more certainly, far more totally than any control that has ever or could ever be achieved by weapons, or by troops of occupation. From space, the masters of infinity would have the power to control the earth's weather, to cause drought and flood, to change the tides and raise the levels of the sea, to divert the Gulf Stream and change temperate climates to frigid. … If, out in space, there is the ultimate position – from which total control of the earth may be exercised – then our national goal and the goal of all free men must be to win and hold that position.[77]

Thus spoke Lyndon B. Johnson in early 1958, shortly after the Soviets had launched Sputnik. There is a *longue durée* of fantasies about and essays in atmospheric manipulation, of which geoengineering is but the latest instance.[78] In *Fixing the Sky: The Checkered History of Weather and Climate Control*, the classic environmental history of this legacy, James Rodger Fleming returns to the rainmakers among Native Americans and the weather stories in Greek mythology (cases that might have pleased Freud).[79] The modern ideal of artificial engineering of the climate can be traced to Francis Bacon.[80] European colonialism gave further impetus to the sorcery, culminating in Atlantropa, a German scheme for closing off the straits of Gibraltar with a giant dam so as to speed up the Gulf Stream, warm up northern Europe, green the Sahara, lower the levels of the

Mediterranean and effect a complete restructuring of the climates of Europe and Africa, to be fused into one continent for one people: the whites.[81]

But if there is one theme that runs unbrokenly through the history of weather control over the past two centuries, it is that of military power. Armies have always taken an interest in weather conditions, as these can determine the outcome of battles.[82] The Civil War sent the minds of some American strategists down the path of rainmaking.[83] It was only after 1945, and more particularly in the context of the Cold War, however, that military thinking about weather control came into its own. This has some bearing on the future of geoengineering, because there is a path dependency that draws it onto the tracks of planning and strategising for military mastery, whether the rationalist-optimists like it or not; Wagner, for one, thinks it would be damaging for the technology to fall under the control of generals, as they would deprive it of rationality. It ought not to be perceived as 'a military project'.[84] But it has always been one.

Already in the 1940s, some enthusiasts within the US military mused about how weather could be turned into a voodoo doll against an adversary. 'The nation which first learns to plot the paths of air masses accurately and learns to control the time and place of precipitation will dominate the globe,' one general from the Strategic Air Command prophesised.[85] As much destructive energy could be poured down on a target by releasing the forces of the weather as those of the atom.[86] By the 1950s, this stratagem had found its place on the Cold War chessboard.[87] The Communist threat had to be beaten back by any means, including meddling with the clouds on which the Soviets relied for their water. But fear was rife that the Soviets would get there first, just as they had conquered space with the Sputnik satellite.[88] Some men of the war machine urged a federal weather modification program. One was Edward Teller, who sat in front of a Senate military preparedness committee in November 1957 and invited his esteemed audience to 'imagine a world in which the Russians can control weather in a big scale where they can change the rainfall over Russia, and that – and here I am talking about a very definite situation – might very well influence the rainfall in our country in an adverse manner'.[89] This was the same Teller who went on to become a spiritual father of geoengineering as we now know it.

The Pentagon could see the allure. It considered how it might ‘tame the winds in the service of an all-weather air force or, on a larger scale, perhaps disrupt (or improve) the agricultural economy of nations and alter the global climate for strategic purposes’.[90] One of the advisors to President Eisenhower in 1953 published detailed ideas for how it could be done. There would be ‘weather-control planes operating from Western European bases’ with the capacity ‘to deluge any selected area of Russia with heavy rain, disrupting lines of supply or movements of armoured units by causing truck convoys and tanks to bog down in mud’.[91] The planes would drop balloons in the jet stream, which would ferry them to their intended destination; there, they would explode and penetrate the clouds with particles so as to induce them to release their water. It was not against the Soviets that this idea was eventually put in practice, however, but against rebels in the South.

Best-known, despite being top-secret, is Project Popeye, an operation for supercharging the clouds over Indochina to flood the Ho Chi Minh Trail, impede the movements of the Vietnamese resistance and prevent it from transporting fighters, weapons and provisions into the South. The rebels of the National Liberation Front would be drowned in rain and mud. Landslides would bury them and whatever they carried. (One of the people who advocated this strategy was Teller.)[92] Between 1967 and 1972, the US carried out over 2,600 flights over the jungles of Southeast Asia, each dumping several loads of silver iodide in the hope of making it rain.[93] Whether this had any impact at all is uncertain. Drowning the resistance proved to be a dud; some studies indicated that cloud seeding could increase precipitation by at the most 10 per cent – hardly a game-changer – while others suggested zero effect.[94] This was magical counterinsurgency. The same applied to the period as a whole: climate modification entered the Cold War despite the fact that it was ‘a weapon that nobody actually possessed’, as Jacob Hamblin notes in *Arming Mother Nature: The Birth of Catastrophic Environmentalism*.[95] Scientists conjured up the trick of rainmaking, and before it was a workable proposition, military apparatuses – the Soviet, but even more so the American – seized on it as a potential queen in the geopolitical chess. Then what happens if, or when, the technology makes the leap from playing at rain to controlling the atmosphere for real?

Geoengineering would manipulate the climate system as a giant totality, not this or that weather front. One cannot even hypothetically deploy sulphate planes to deluge a Russian harvest. One cannot integrate them directly into a counterinsurgency campaign as one could – if only on paper – cloud seeding. They do not have the minimal precision of a weapon: the 'long time scale and spatially diffuse climate changes produced by geoengineering appear to lack a credible military use', Keith has concluded.[96] Yet this is rather to miss the point. Geoengineering would be rife with indirect military use, insofar as *side effects* emerge and the injector is less concerned if these befall foes than friends. Indeed, one cannot rule out that it could – if the operation attains anything like the fine-tuned design the promoters envision – calibrate doses so as to inflict harm. Iran without rainfall might be less of a bother than a strategic benefit. Given the temporality of side effects, the potentials for weaponisation of the planes will grow over time. Moreover, geoengineering would represent a kind of *universalised* counterinsurgency or campaign of repression; and surely this was the significance of Stardust Solutions, as juxtaposed to Project Popeye. The former did not seek to collapse the tunnel system of the Palestinian resistance by means of planes. It merely readied the world for a scalar jump, by which the kind of military means hitherto used to combat a narrowly defined enemy would be turned against the entire set of contradictions that make up the climate crisis, somewhat like cutting a Gordian knot with a missile. Or, in this crisis, it is the recalcitrant Earth itself that shakes off the fossil occupation – every avalanche a mute riot – and the occupier responds as it is wont to: autonomous nature as the Other, the ultimate enemy that must be destroyed.[97]

Squeamishness about such militarisation is not unwarranted. It might well capsize what little rationality might remain in the operation. The postwar prehistory of geoengineering here has ample lessons to offer, particularly in the art of mixing atomic and climatic explosions. Already in 1945, one scientist in the UK argued that instead of dropping nuclear weapons on cities, one should use them as 'atomic dynamite' to blow up parts of the 'Arctic Cap'.[98] In 1958, the director of meteorological research at the US Weather Bureau picked up the idea. He took to the pages of *Science* to consider the possibility of detonating 'ten really "clean" hydrogen bombs, of 10 megatons each, at optimum depth in the Arctic Ocean' to create an 'ice cloud' that would trap outgoing radiation and

thereby accumulate more heat in the region.[99] Such induced warming – geoengineering with the opposite sign – would improve conditions for agriculture and other economic activities in the northern latitudes.[100] In the end, of course, no one ventured to blow up the sea ice. Its decline necessitated no bombs of this kind.

Teller had an even spicier idea. He wanted nuclear weapons to serve more specific purposes for mankind: enhanced oil and coal recovery. They ought to be detonated to 'heat the Canadian tar sands, allowing the crude petroleum to be pumped to the surface in a liquid state' and to blow resistant rocks to pieces, forcing them to give up their hidden oil.[101] In Project Chariot of the late 1950s, Teller and his colleagues sought to convince the people of Alaska that five nuclear bombs off their coast would profitably gouge out a deep-water harbour for the export of coal. Their combined explosion would have a power 160 times larger than that wiping Hiroshima off the map. It would, Teller eagerly alleged, carve out the harbour in no more than two seconds. Parts of the Alaskan elite were apparently receptive to this reasoning. 'What objections could there possibly be to this large-scale atomic harbour-blasting project?', one local newspaper asked, without intended irony.[102] The designed location for the megablast was Cape Thompson, on the unceded lands of the Inupiat people. When Teller was pressed on what these people would do once their traditional hunting and fishing grounds had been obliterated, he responded: 'They're going to have to change their way of life,' adding that 'when we have the harbour, we can create coal mines in the Arctic, and they can become coal miners'.[103] Teller came close to realising this idea, but ultimately various kinds of resistance killed it – a reminder that at least occasionally, reason has in fact prevailed over technological feasibility.[104]

From the heydays of the A-bomb, generals of the West maintained an interest in the atmosphere as a medium of war. In the early 1960s, NATO consulted Teller and others on the option of using hydrogen bombs to 'alter global climate for long periods'.[105] In 1996, a study presented to the US Air Force talked up the prospects of the military of this nation 'owning the weather' in the near future, more precisely in 2025 – a 'high-risk, high-reward endeavour' not unlike 'the splitting of the atom'.[106] In 2003, an internal report to the Pentagon was *au courant* with the breakdown of gradualism in climate science; it warned of the geopolitical effects of what

would soon be known as tipping points and recommended not mitigation – an option passed over in silence – but the exploration of geoengineering (here mainly imagined as the release of ultra-potent greenhouse gases to counter the cooling effects of an AMOC collapse). But that technology would have to be studied carefully, given its 'potential to exacerbate conflicts among nations'.[107] The CIA and various branches of the Pentagon stayed abreast of developments, and the basic research at Harvard – possibly fizzling out after the SCoPEx fiasco – had close links to the intelligence and defence communities, taking this story of entanglements up to the early 2020s.[108] It is not necessarily conspiratorial to assume that such actors kept an eye on the experiments and ever-more frequent trial balloons in those years. Reports about an outfit like Stardust would surely have found their way to the right desks at Pentagon.

What is the deeper meaning of this imbrication between bombs – atomic in particular – and sulphate planes? Both bring to life a desire for total domination. In psychoanalytical terms, this means that the planes could be charged not only with magic and repression and libido, but also with the death drive. Military violence is the privileged realm of this drive, which, as is well known, can be both outwardly destructive and self-destructive.[109] (Teller could be its caricatured representative.) If geoengineering were to become tied up with narcissistic rages of destruction, it would not bode well for anyone involved, the empire included. Adjacent to such theories are those of Günther Anders, perhaps the critical thinker of the postwar period most deeply troubled by the bomb, next to whom 'Adorno seems like an optimist'.[110] In an essay on his legacy in a warming world, Jacob Blumenfeld has pointed to one central difference between the threat of nuclear and that of climate apocalypse: the former would happen through an action – a push of a button – suddenly shattering daily life; the latter would rather be a guaranteed outcome if things continue to accumulate as they are now. There is no bombshell logic to fossil fuel combustion. But there is one to geoengineering. 'It is the one attempt to live up to the disaster by out-disastering it', an atomic bomb for getting on top of the slow-burning fuse.[111] It would bring the dynamism of nuclear war into climate politics, in a manner that may well have delighted the original cold warriors.

But there is no reason why geoengineering should have a monopoly on the nuclear option. In early 2025, an early career scholar at a university in the state of New York – a computer engineer, with stints at Microsoft and

Lockheed Martin on his CV – unveiled yet another fresh solution to the climate problem: build the largest nuclear bomb ever and detonate it beneath the seabed.[112] It should be about 4,000 times bigger than the bomb dropped on Hiroshima.[113] It would serve up so much pulverised rock for enhanced weathering as to remove 1,000 gigatonnes of CO_2 in one blow. No need to mine and crush and transport powder. The bed under Kerguelen would be the ideal site: barren, faraway, out of view. Granted, radiation from the blast might drift towards people, but 'this explosion is so remote and can be timed favourably with the weather, there is little to no expected loss of life'. The costs from climate change thereby averted would yield a '10,000x return on investment' on building just one bomb – 'the obvious cause of action financially'. It would also be politically exigent. 'As rising sea levels and extreme weather events displace populations, countries are facing growing numbers of climate refugees, which strains international relations and necessitates new migration policies.'[114] Keep the non-whites away, blow up the seabed.

A little plea for contingency

'From my current vantage point', writes Smith, the commencement of geoengineering 'looks as if it would be among the most consequential decisions in human history'.[115] On this, he cannot be gainsaid. It is only slightly easier to shake off the impression shared by so many students of the phenomenon: that it is inevitable.[116] Stratospheric aerosol injection might still seem theoretical in the middle of the 2020s; but it can also appear like destiny. It is simply too easy to do, with too immediate apparent gains in temperature reduction, poised against too overwhelmingly extreme dangers from untreated heating, for it to go untested. One day, someone – not anyone, but someone – will do it; perhaps one day soon, perhaps in the early 2030s, perhaps a little later.[117] But if geoengineering is nearly inevitable, the termination shock, in turn, looks only slightly less so.

The dynamics impelling the operation towards that endpoint are, as we have seen, immanent to it; but the rationalist-optimists have focused their rebuttals on the exogenous triggers. Terrorists can be stopped in their tracks. Just guard the facilities.[118] In the unlikely event that they were to succeed

and paralyse the global injection system, ‘humanity would have a period of several months’ to turn it back on, a job made easier if there is back-up hardware.[119] The infrastructure should have a copy in reserve that can be activated in case of a knock-out blow. But this would, of course, duplicate the sensitivities, guard duties, coordination requirements and other logistical challenges: instead of one system, the geoengineer would have to maintain two – a double layer of militarisation. Or perhaps three, an additional shadow infrastructure to protect against a crash in the second?[120]

In their efforts to belittle the problem, the rationalist-optimists habitually point to other systems that have been kept in unbroken operation despite stress. Did not the Dutch maintain their dikes through two world wars?[121] Has not the world succeeded in maintaining ‘trans-oceanic communication links and electric power grids for more than a century in spite of horrific wars’, or healthcare and farming systems, not to mention satellites?[122] And the internet? All these vast, complex technological apparatuses have withstood strain and continued to function 24/7 worldwide, and so, the argument goes, we should expect the same resilience from stratospheric aerosol injection. But it overlooks the paramount difference: none of these putative analogues has a tendency to produce a rising tide of negative side effects on ecosystems. Dikes and satellites do not tip clouds or crops into collapse after some decades of enhanced operation. They do not attract the anger of those on the receiving end of the chaos, who seek retribution. They do not tend towards a termination shock, as they lack the inbuilt law.

But, the rationalist-optimists insist, geoengineering will be done moderately and temporarily – this is how we want it! – so the mask will remain thin, the combination ideal and the risk low, as prescribed in our idealised models.[123] Groundless as this optimism is, it sits alongside the opposite argument, advanced whenever the shock is mentioned: ‘If the world wanted to continue flying dozens of planes into the stratosphere around the clock, chances are it would be able to do so.’[124] That is, termination will not happen. We need not lose any sleep over it, because the world will find a way to keep injecting aerosols in perpetuity.[125] We can do it forever, so let’s go – an argument that obviously undercuts any pretensions to minimalism and sets up precisely the journey towards shock. For the longer the journey goes on, the more severe the risk, the greater the incentive to continue, the worse the accumulation of side effects (and the

longer the exposure to exogenous jolts to boot), until the geoengineered world reaches some breaking point.[126]

If this world becomes determined by imperial violence – a considerable risk, as we have argued – the side effects might well become even more ungovernable than if the agent is the picture of serene reason. Rationalist-optimists would like to think that if they do become genuinely unendurable, the sunshade could be dialled down gradually, gently, to avoid the shock; this would be the rational way to do it.[127] 'The risk of termination might not be so great. Unexpected negative environmental effects might be detected early [*sic*], and solar geoengineering could be ended slowly instead of suddenly.'[128] But this gradualist wish seems as pious as that for a similarly charted inauguration. Just as the climate crisis will have to reach some critical state before geoengineering is switched on, so will a crisis of side effects before it's switched off. If there is anything the former has taught us, it is that gradualism is false in general and that, very much in particular, capitalist society is inert and blocks incremental change. It is more likely than not to let pressures build up to the point – itself unpredictable in time and character – at which it eventually flips into another state or course. Non-linear, punctuated change is the rule not exception. Geoengineering will be a shock when it comes and when it goes. When a group of scholars including Niles Eldredge, colleague of the late Gould, surveyed the jagged landscapes of punctuated equilibrium in 2024, they began with the K-T event and ended with the prospect of geoengineering, from which we can expect 'feedback and accelerated responses to long-term shifts': there will be avalanches writ large.[129]

But even if they do not make it as they please, and even if they do not make it under self-selected circumstances, but under circumstances already given and transmitted from the past, it is human beings who make history. Whatever traditions and nightmares weigh them down, at the end of the day, nothing is truly inevitable. Whether geoengineering will occur depends, among dozens of other variables, on what position popular and progressive forces take on it. Will there, as Keith has long feared, be riots against geoengineering too? Should there be?

Conclusion

After the Deadlines

The good news for revolutionaries, in a cynical manner of speaking, is that the multiplication of fronts under overshoot supplies so much more raw material for interventions. Every technology introduced from above is like a grain of sand on the pile that is society. It introduces yet more contradictions into a system already straining and groaning under the pressure of too many. In its warming condition, late capitalist society may be approaching a nodal line of its own – the gist of a subfield of research forming just as the overshoot conjuncture dawned. In the first years of the 2020s, academic journals filled up with articles on 'positive tipping points' as a source of hope.[1] 'We have left it too late to tackle climate change incrementally,' read a typical first sentence.[2] Because the world was running out of time for gradualism-reformism, the only light in the darkness would come from a spark flashing up suddenly, classic revolutionary style: 'Ironically, we see hope in the non-linearity of the human realm of the earth system, which is even more prone to abrupt transitions than the climate itself.'[3] One reason for this scholarly vogue, apart from the vanishing time for non-revolutionary reforms, might have been the unexpected surge in climate activism in the late 2010s; but even after it petered out, the basic contention remained valid.[4] Nothing can save us other than an avalanche in the prevailing order.

What would it look like? One candidate can be quickly dismissed: a tipping point activated when renewable energy yields more profits than fossil fuels.[5] We demonstrated in *Overshoot* why such a moment will never come. Far more plausible – indeed, the most realistic of all scenarios for a

positive point – is a collapse in the value of fossil fuel property. It could bring down most circuits of capital accumulation. ‘An avalanche effect would be triggered if national banks and insurance companies warned against the global risk associated with stranded assets from fossil-fuel projects.’[6] We described in extenso how such a meltdown might unfold in *Overshoot*; here, we must add that, in this conjuncture, the task for revolutionaries is *to use any crisis to return to the unaccomplished mission of attacking investment in fossil fuels*. Only if contradictions opened up at a secondary front are brought home to the primary front of mitigation can the requisite avalanche be touched off. Only if the raw material is refined into explosive devices placed under fossil capital, as it were, can the outcome be positive, in the strict sense of the term. Any slides in the social pile must be consciously directed towards this point, or the ball conducted into the right basin of attraction; the research in the early 2020s spoke frequently of *deliberate* tipping.[7]

The literature thereby gestured at the qualitative difference – not to say ontological abyss – between tipping in nature and in society, between catastrophe and revolution. If it gets 4°C hotter on Earth, we can be reasonably certain that the Greenland ice sheet will long have passed its nodal line and entered the last avalanche. But in a 4°C world, masses of people might be as passive as they were around 1.5°C. There are no mute physical processes that set them marching towards the Winter Palace of their time. Tipping in society hinges on a faculty that still constitutes the *differentia specifica* of human beings: agency.[8] Grains of sand do not intend to bring about the cascade. Here they differ from revolutionaries, who are always present on the scene when the metaphorical grain hits the creaking pile of society, there to steer the slides – the initial spontaneous outbursts – into a sustained process of revolution: the vanguard of seasoned activists distributing the first leaflets in Gaza in December 1987, or in Tunisia in December 2010, to return to two previous examples. One fracture in a glacier does not exhort the neighbouring patches of ice to come and join the rally.

The only thing climate revolutionaries can expect to have at hand, then, is raw material in ever greater abundance. They are a bit like gold prospectors stumbling into a valley of seams and deposits that appear positively to grow along the hillsides, but who as yet lack the necessary equipment; at most they possess hazy ideas about how to get at the desired material. Non-

revolutionaries, too, can make out the contours of this landscape. ‘I can imagine riots that may coalesce into widespread armed insurrection as tens if not hundreds of millions of people watch their homes claimed by the sea and their crops wither,’ shudders Wake Smith.[9] The riots in Khuzestan and Valencia were early harbingers. As seen from the revolutionary camp, this is the terrain of raw materials, and the strategic horizon is, first of all, to break the doom loop: find the proper tools for intervening in the moments of crisis, then reroute its energies onto the ultimate source of the problem. No one knows how quickly the business of fossil fuels could then come undone.

It bears repeating: no one knows. In *Hopeful Pessimism*, a wellspring of wisdom about how to live and act in this conjuncture, Mara van der Lugt argues that only one criterion needs to be fulfilled to keep the flame of hope alive, however tiny, however feeble and flickering: uncertainty.[10] As long as there is uncertainty about the outcome, there is reason to hold on to the belief that action may yet make a difference. Only a future fully known in advance, a guaranteed unfolding of history in one direction only, extinguishes, by definition, the last hope. Now it so happens that our times are pregnant with uncertainty *precisely because they are so generative of disaster and destruction*. ‘The future is dark, which is on the whole, the best thing the future can be, I think,’ van der Lugt quotes Virginia Woolf.[11] But we might as well quote an actual revolutionary who made a similar point: ‘We do and cannot know which spark – of the innumerable sparks that are flying around in all countries as a result of the economic and political world crisis – will kindle the conflagration; we must, therefore,’ urged Lenin, ‘set to work to stir up all and sundry, even the oldest, mustiest and seemingly hopeless spheres, for otherwise we shall not be able to cope with our tasks.’[12] Only the adjective ‘ecological’ here needs to be added before ‘world crisis’. It is not because the future is radically open and can go any which way – good outcomes as likely as the bad – that a moment remains for action. Rather, and quite evidently, ‘current conjunctural trends have no longer-term direction other than generalised devastation’, as recently observed by Oliver Eagleton.[13] But devastation has a way of eluding the control of its authors and cracking the hardest structures and sending sparks flying. A world on fire is also one where firebombs can be picked up and thrown on target.

‘The bourgeoisie commits the country to devastation by our bitterest enemies, it squanders our life like some trifle, and it produces disaster wherever it turns,’ noted a resolution from a soldiers’ committee printed by *Izvestiia*, the organ of the Petrograd soviet, in September 1917.[14] When the least expected event – an actual revolution – did take place, Russian papers filled up with analogies to the natural world.

> Like a quake deep in the earth, breaking everything, the revolution appears before us: it appears like a hurricane, sweeping aside forms … The revolution recalls nature: storms, floods, waterfalls. Everything in it breaks ‘across boundaries’; everything in it is excessive.

Or ‘all revolutions come unexpectedly. This is the real grandeur of their arrival. They are born spontaneously [*stikhiiono* – literally, like the elements]. They fly in, like a hurricane, and tear out freedom for the exhausted people.’[15] Leninist theory was the gloss on this lived experience. It now also has a rigorous scientific foundation: basins of attraction, punctuated equilibrium, self-organised criticality, tipping points, the whole ensemble of related concepts. After the actual revolution was succeeded by absolute catastrophe, and because the longing for disruptive agency bends towards the divine, Walter Benjamin sketched the most significant theologico-philosophical elaboration of Leninism: for the devout Jews, ‘the future never became homogeneous, empty time. For every second was the small gateway in time through which the Messiah might enter.’[16] His weak messianism has its non-metaphysical counterpart in the science of positive tipping points.

In the age of technological destruction, Günther Anders clung to this bleakest of all hopes, seasoned with drops of theology, as did Hannah Arendt.[17] Veering between natural analogues and mysticism, she considered acts of freedom profoundly improbable. But was not also the emergence of planet Earth a singularly unlikely event? The formation of organic life? The evolution of the human species? All of these could be deemed miraculous events, without necessarily slipping into full-blown religion; as for human affairs, apparent miracles have occurred frequently enough to justify faith in their possibility.

> Hence it is not in the least superstitious, it is even a counsel of realism, to look for the unforeseeable and unpredictable, to be prepared for and to expect ‘miracles’ in the political realm. And the more heavily the scales are weighted in favour of disaster, the more miraculous

> will the deed done in freedom appear; *for it is disaster, not salvation, which always happens automatically* and therefore always must appear to be irresistible.[18]

Perhaps this is close to the essence of ‘hopeful pessimism’, a resource indispensable for travelling deeper into the heat. After the deadlines, paradoxically, the weight of the contradictions will grow so much that the small gateway in time might do so as well – up to a point. Before then, it is too late to give up.

Running in the tragedy loop

So, should climate activists react to the next combined heatwave and drought by forgetting about the golf courses and the *mégabassines* and just strike at the headquarters of Total? A call to focus exclusively on mitigation would be facile. It is too late for that too. Overshoot is constituted by what we might call a *tragedy loop*: the more adaptation, removal and geoengineering serve to delay emissions reductions even further – the more they function as substitutes for mitigation – the more necessary they actually become. There is no escaping them, precisely because they have allowed fossil capital to escape destruction. Substitution is a self-fulfilling prophecy, from the first musings of the Nordhaus crowd into the middle of the twenty-first century and beyond.

But compounding the tragedy loop is the fact that *none of these three will ever work without revolutionary mitigation.* We have seen this law reappear on every possible front: no substitutive technology can function as such; from muscular adaptationism to stratospheric aerosol injection, the notion is self-destructive. This is perhaps most evident in the latter case, where any non-apocalyptic outcome presupposes that the sky be emptied of excess CO_2 through complete mitigation plus removal. And that, in turn, requires that negative emissions technologies be divorced from late value form and wedded to a project of capital destruction. In the mess that is overshoot, the success of the three prongs is contingent on that of the others *and most fundamentally on the mitigation for which they stand in.*

If there is any way out here, it hinges on a great deal of political precision and striking power and ‘unity of the fronts’.[19] Battles on them all would

need to be coordinated and continuously refocused on fossil capital itself, even as they concern surviving its fallout. Sharing the scarce water must be combined with an assault on the force that drains the earth. And if the former ever happens, the likelihood of the latter might naturally rise: a city ruled by the councils of the vulnerable would be more inclined to shut down fossil fuel properties than one where death is distributed along class lines. Revolutionary adaptation and mitigation would here go together.

This would be the ideal type of climate politics when it's too late; less ideally, adaptation will be the front into which the others dissolve. Mitigation might never come about. The same applies to removal and geoengineering. The only certainty would then be that people will have to run through this battlefield and try to save their own skins. Progressive forces can never again have the luxury of staying away from the adaptation front: in the end, it might be the only one. And that would also be the tragedy consummated.

Removing removal

In the very concept of overshoot lies the necessity of removal. It now corresponds with hard material realities. Once 1.5°C – or any other threshold we might set – well and truly lies behind us, the remaining choices are two: submission to the heat already here or preparation for the battle for reversal. Whether mitigation emerges victorious tomorrow or on the killing fields of 3°C, the combustion of the past continues to impose itself. Negative emissions technologies cannot then be rejected wholesale as a matter of principle, although arguments for doing so have been adduced: something like DAC is forever tainted with capitalist origins.[20] But much the same could be said about several renewable energy technologies. They too have been pasted onto business-as-usual and used to create false impressions of sustainability. Should we therefore conclude that we must do without solar and wind to stay clean? DAC and photovoltaics here inhabit the same battlespace: fossil capital deploys them to reproduce itself; counterforces would arrange them to maintain a habitable planet. A second argument would be that all technologies of removal have side effects. But so do, again, those of a 100 per cent flow economy. You can despoil whole

landscapes and deplete resources and displace communities through ill-advised upscaling of solar and wind (not to mention hydropower). Even the most hard-headed proponents of vegan diets and public transportation need to account for how legumes are grown and highspeed railways cut through hillsides.[21] A third argument would be that removal is utopian: but so, of course, is a Green New Deal, degrowth, ecosocialism …

The question is then resolved into another. *How* should removal be done? We have seen what the first response and rule must be: on a limited scale. Unlimited, unbound removal would trash the planet. And this takes us back, once again, to the alfa and omega of climate politics, which is mitigation. The burden to be removed must be held at an absolute minimum. The first instruction in every reasonable manual for a negative emissions technology is to keep fossil fuels in the ground. Following it would mean inverting every actually existing trend, the spinning of which forms the tragedy loop; but were this to be accomplished, one could begin to set up the various technologies like so many little leaves for capturing dew drops.

Rewilding and regeneration of forests and agroecology would be put in place first. Planned well, they would be the most universally benign; and therefore also, as we have seen, the weakest. They might not survive the heat but should be done regardless, to protect nature for its own sake; any removal in the wild can then be welcomed as a bonus. They could perhaps be supplemented with a smattering of vegan BECCS. It could have benefits reverberating on the other fronts. By shutting down animal agriculture in the North, emissions would drop and mitigation ensue; and a majority of these emissions would be of methane, not carbon dioxide. Unlike CO_2, CH_4 has a short residence time in the atmosphere. If humanity were to stop pumping methane from cows into it, there would be a comparatively rapid reduction of the gas; within a decade or so, the atmospheric concentration would drop, and then so would temperatures. Studies suggested that up to 0.2°C of warming could be taken out in this way: not an enormous amount, but perhaps sufficient to bring about some real relief in moments of deep need.[22] Here, then, is something truly unique: mitigation, removal and peak-shaving all rolled into one; the wholesome vegan route out of overshoot, no solar geoengineering needed.[23] (Note that abolition of the meat industry would not be dictated by culinary preferences. Humanity only has so many options left.)

Even vegan BECCS would, of course, need to keep the consumption of water and fertilisers in check and contain any negative effects on biodiversity. Monoculture plantations would here not be admissible; best if the freed-up land were first put to other uses and selected waste streams recycled for removal. Add some pinches of biochar into this mix and a measure of well-crafted enhanced weathering and you would have a soup of drawdown brewing, albeit very thin. The real fibre would have to come from elsewhere, and here DAC currently appears to be the most digestible candidate. We have seen what best-case deployment would look like: DAC hubs built on the sites blessed with the greatest superabundance of solar and wind, followed by mineralisation (insofar as it works).[24] A diversity of tactics would have advantages as such. Rather than one-size-fits-all – as when IAMs rely exclusively on BECCS and forestation – a suite of options could be restrained, modulated, adapted to local circumstances. If a soup is brewed with many ingredients, it does not have to exhaust supplies.[25] But such temperance would only work if society does not make itself dependent on humungous quantities of soup: then even the most variegated mix would have to devour every larder. Progress would thus once again presume mitigation, as well as successful resistance against the most destructive kinds of late technopower. More decisive still would be the fight against late value form.

Capitalist property relations strap negative emissions technologies into the straitjacket of exchange-value: because sequestration can produce none, they are distorted for other purposes. No one on Wall Street will ever pay for cleaning up mountains of atmospheric waste just for the use-value of it. Removal would have to be the collective good par excellence. Publicly funded, democratically governed, it could only ever materialise if snatched from the jaws of value in general and primitive fossil capital in particular. First and foremost: not one tonne of captured CO_2 can be swallowed by enhanced oil recovery.[26] The practice must be banned. Fossil fuel companies have to be thrown out of the ‘space’ of removal altogether. Indeed, their liquidation is a premise for any meaningful removal; and to the same extent, they cannot be allowed to come anywhere near it, any more than one would load a water bomber with napalm. A minimum reform would be to make it illegal for fossil fuel companies to purchase removal startups; but this would merely be a prelude to their criminalisation as

such.[27] Offsets would have to go the same way. A minimum reform could be to eliminate the cheapest and junkiest credits, restrict the market to durables solely and regulate what they could be used for. But stop-and-reverse demands more than this: not even the most pristine offsets could deliver reversal, because they would still be offsets, underwriting ongoing emissions elsewhere. The whole market should simply be closed down.[28] This would involve stranding billions of dollars' worth of assets – the capitalised pseudo-removal sector another sphere in for destruction.[29] Commodification in all its guises would have to come to a full stop.[30] Permanent removal is preceded by the end of late value form.

This entails rejecting the notion that only the market can incubate the embryo of negative emissions technologies. There is strength to the argument that a tech like DAC needs to be nurtured immediately, even if massive rollout is still decades into the future; a mature complex cannot be summoned *ex nihilo* in the year 2044. Time first has to be devoted to mastering the engineering challenges – 'To get more practice in. You've got to shoot more goals,' in the words of Nicholas Eisenberger. But if this hatching period is given over to capital, the technologies will inevitably be lost to late value form. DAC reared by private companies will be DAC shackled to the production of oil or offsets or commodities. The alternative is plain to see, from centuries of technological development: states breeding the productive forces, like the most crucial weapons in wartime (perhaps the only palatable analogy with atomic bombs).[31] States would have to assume full responsibility for growing removal capacity. States would have to finance it, own it, direct it, enforce it and keep it away from the bottomless pit of value.[32] One could imagine 'carbon removal administrations' in each country or 'a centrally planned sector, with publicly deliberated and adaptable volumetric targets integrated with other climate action' – a People's Commissariat for Removal.[33]

Proposals are already floating on the utopian current of ecosocialism. Why not nationalise fossil fuel companies and convert them into organisations for sequestering CO_2? Compel the polluters to clean up their own mess; put their geological and chemical expertise to some good use; transfer workers in this doomed industry to new jobs, without having them move one mile. The company formerly known as ExxonMobil: a public utility for drawing down all the emissions it caused and then some.[34]

Similar things could be done to the auto industry. Lackner and other apostles of DAC have often calculated that 10 or 20 million DAC machines should be manufactured every year and claimed that this is entirely within the realm of possibility, since more than 70 million cars – devices of comparable size and sophistication – are turned out annually from the world's factories.[35] But the contention would be more credible if it came with the proposal that one fourth of the auto industry be *converted* to DAC manufacturing. Under the regime of this Commissariat, the pace of technological development could be forced. Secrets from startups would be acquired and knowledge about negative emissions technologies circulate freely, no patents secluding it. No laissez-faire on the oceans or any other ecosystems; no private plunging into projects ahead of the science. There would have to be late technopower but in another mode: no riding roughshod over communities, a fair sharing of the burdens.[36]

Some throw up their hands at such ideas. They view them as 'so remote from reality as to be practically irrelevant'.[37] Might we here after all be descending into the realms of pragmatic naivety, unwittingly joining the architects whose ideal designs for the future end up providing 'cover and legitimacy to fossil fuel and other corporate interests' in the present?[38] Is all this, in the end, nothing more than the left version of rational-optimism? Not exactly, because what distinguishes the latter is an explicit acquiescence to business-as-usual; a serious commitment to stop-and-reverse would rather be the opposite. Confronting fossil capital is the opening move on which the rest of this game hinges. A left programme for removal would be identical to a frontal assault on the causes of climate destruction, a shutting down of the prime movers of irrationality.[39] To argue against it on the grounds that it is too good to come true is to downplay the possibilities for mitigation.

The tragedy of overshoot is then inverted into an irony: precisely the revolution that overshoot was meant to avoid *would have to be replicated on the removal front*. In this, overshoot mandated not one but two climate revolutions rolled into one. Should the latter succeed, however, they would inherit a much-scorched Earth. Even the best-case version of communal removal might fall flat on the tipping points. And the scale problem refuses to go away. To reverse temperatures back to pre-industrial levels would require taking out 2,500 gigatonnes of CO_2 – a figure based on the

emissions accumulated until 2022; it will have grown since then.[40] On optimistic calculations, a sustained effort to remove 10 gigatonnes per year could yield a cooling of around 0.05°C per decade.[41] Removing all of the 2,500 gigatonnes and undoing a warming still below 1.5°C – this, again, starting from the year 2022 – would then take about two and a half centuries. But could a Commissariat that respects people and nature ever reach as much as 10 gigatonnes per year?[42] If not, any reversal would take *more* than just a couple of centuries. And that is a forecast from *before* the overshoot of 1.5°C had set in …

If this sounds disheartening, it merely underscores, once again, the uncompromising centrality of mitigation: nothing can stand in for that task. This is the principle that must guide climate politics after the deadlines. Until emissions have ceased, talk of reversal has something futile and redundant about it, rather like contemplating the restoration of a river delta spoiled by an oil spill while the leak is still spewing from the tanker and nothing is being done to stem it. That would be a mind distracted. We can here amend our response to the critics: progressive climate politics requires not that we desist from removal in principle, but that we develop a crystal sharp sense of priority. In the present moment, there is one thing to be done, one thing first and one thing before anything else. Here is the case for spending every kilowatt-hour on eliminating fossil fuels. Not an hour or dollar should be diverted to DAC or any other such tech that could still be spent on the primary front – hence the rule of reserving hubs for sites of superabundance. For the sake of removal itself, any near-term scaling plans, let alone lofty reversal ambitions, should be put on the back burner. As long as emissions continue – grow, even – the whole question ought to be put to the side; meanwhile, negative emissions technologies can be gestated *in vitro*, so that they can one day have some use-value, however limited that might turn out to be. This chain of priorities runs against efforts to close any ‘carbon removal gaps’ that might be identified in the present.[43] It rather mandates that we throw all the force we can muster into the fight to close another, ever-widening gap: between what is happening in late capitalist reality and what must be done, what should have been done long, long ago.

Resisting geoengineering

If DAC and some of its peers can at least hypothetically be extricated from bourgeois madness and put on a sound footing, does the same apply to geoengineering? No technology is a clone of another. Each has its own pattern. A bicycle can be driven by a police officer or by a postal worker, for entirely disparate purposes; a drone can be operated by a resistance movement. But can a border wall ever be built for the cause of emancipation? An atomic bomb? An oil platform? Some productive forces can be unfettered from the relations that have birthed and deformed them; others have destruction encoded so deeply in their constitution that the potential does not exist. Some can move between contexts; others have unidirectional mayhem and repression built into them. Geoengineering seems to fall into the latter category. We have sought to follow the methodological precept of a concrete analysis of the concrete technology; and from what we have seen, it admits of no progressive case for this one. Those on the left who try to make such a case spread dangerous illusions. Rationalist-optimist approaches deserve nothing but hostility. They should be countered with consistently critical pessimism, attuned to the realities of this order. Throwing a nuclear bomb into the climate crisis will not de-escalate or contain it – in the longer run, rather the opposite.

For geoengineering, then, there can only be opposition: uncompromising, Luddite resistance. Does this mean that any sulphate planes should be attacked with riots and sabotage and maybe more? The question must be divided temporally, conjuncturally. In the present, militant action against geoengineering might be justified, because it fortifies denial with the fantasy of repression and accelerates every loop in the wrong direction.[44] The future may yet be another matter. What do we do if the US declares a control emergency in, say, 2040? It could coincide with the mass death of any number of poor people in the global South. Taking down the planes in that moment might not only be inopportune; it could be diagnosed as the worst repression of how bad things are. Excluding such a scenario would in itself be to deny just how catastrophic the breakdown might become in the next couple of decades. If we take the tipping points and all the rest seriously, we would have to accept that a situation can emerge in which geoengineering appears, if only for a fleeting moment, as the lesser evil.

But an evil it would be. The resistance to it might have to announce a temporary suspension of active hostilities, followed by the demand that *the planes be grounded as soon as physically possible*. That might be a

thankless task. But nothing else would have the chance to avert the termination shock. During the sigh of relief, opponents to geoengineering could be hunted down as killjoys and folk devils; but if they do not stick to the position of resistance to this technology, if they do not keep on castigating it whatever the trends in opinion, the lock-in of the shock would be all but certain. Without resistance, there will be only the nightmare of new generations of burning children.

The demand to bring down the planes would then have to be added to an immediate and total phase-out of all fossil fuels (plus removal, Commissariat-style). The revolution is a hydra that grows more arms for each one that overshoot cuts off. Whether it will also win in the end is, of course, an open question; we have argued that resistance not only to geoengineering but to fossil fuels might well become more difficult in the sulphate mist. To keep a light burning through it, perhaps the day of deployment should be a day of fury against fossil fuel property, of mass actions smashing the material embodiments of the compounded crime: if humanity would let itself be herded into a geoengineered world without a fight, with not a memory of a battle on its eve, an exit would become even less likely.

But all of this is evidently speculation, feverish as the tech itself. A concrete analysis of the concrete technology must be coupled with a ‘concrete analysis of the concrete situation’, the original formulation from Lenin: a conjunctural method reserving final judgement for the people active and alive on the day of deployment, should it ever come. It is not for people in 2025 to decide what to do in 2040 or 2060. Climate politics when it’s too late must be subject to revisions and updates. The destruction of fossil capital is the only item that can never move down on its agenda. None of this will be easy; much becomes harder by the day. But no one said this would be easy, and if they did, how wrong they turned out to be.

Malmö, 27 March 2025

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Notes

Preface

1 In this case, Barack Obama during his State of the Union address in 2015: The White House, ‘Remarks by the President in State of the Union Address’, 20 January 2015.
2 On floatovoltaics, see Andreas Malm and Wim Carton, *Overshoot: How the World Surrendered to Climate Breakdown* (London: Verso, 2024), 177–80.
3 Ibid., 37–45.
4 Ibid., 8–21.
5 Ibid., 55–69. For a good summary of the idea, which appeared after we had completed *Overshoot*, see Andy Reisinger and Oliver Geden, ‘Temporary Overshoot: Origins, Prospects, and a Long Path Ahead’, *One Earth* (2023) 6: 1631–7.
6 Malm and Carton, *Overshoot*, for example, 70–2.
7 Ibid., 95–6.
8 Ibid., 99–165.
9 Ibid., 165–6.
10 Ibid., 169–96.
11 Ibid., 196–220.
12 Copernicus, ‘Global Climate Highlights 2023: Copernicus: 2023 Is the Hottest Year on Record, with Global Temperatures Close to the 1.5°C Limit’, June 2024.
13 Jeff Tollefson, ‘Earth Shattered Heat Records in 2023 and 2024: Is Global Warming Speeding Up?’, *Nature* (2025) 637: 524.
14 On the loss of influence of this natural oscillation over the trend of accelerating warming, see Alex J. Cannon, ‘Twelve Months at 1.5°C Signals Earlier than Expected Breach of Paris Agreement Threshold’, *Nature Climate Change* (2025), online first; Tollefson, ‘Earth Shattered’, 523–4.
15 Jonathan Watts, ‘Unprecedented Number of Heat Records Broken Around World This Year’, *Guardian*, 14 August 2024.
16 Chiwoyu Sinyangwe and Rachel Savage, ‘“I Have Lost Everything”: Southern Africa Battles Hunger Amid Historic Drought’, *Guardian*, 14 November 2024.
17 Martina Igini, ‘Drought-Stricken Brazil Sees 80% Yearly Rise in Wildfires in 2024 as Toxic Smoke Spreads Across the Country’, Earth.org, 2 September 2024; Earth Observatory, ‘Smoke Fills South American Skies’, 3 September 2024.
18 Earth Observatory, ‘Intense, Widespread Drought Grips South America’, 21 September 2024.
19 Jeff Tollefson, ‘Earth Breaches 1.5°C Climate Limit for the First Time: What Does It Mean?’, *Nature* (2025) 637: 769; World Meteorological Organization, ‘WMO Confirms 2024 as Warmest Year on Record at about 1.55°C above Pre-Industrial Level’, 10

January 2025. On the extreme weather events of the year, see Friedrike Otto, Joseph Giguere, Ben Clarke et al., ‘When Risk Becomes Reality: Extreme Weather In 2024’, Climate Central and World Weather Attribution, 27 December 2024.

20 Emanuele Bevacqua, Carl-Friedrich Schleussner and Jakob Zscheischler, ‘A Year above 1.5°C Signals that Earth Is Most Probably within the 20-Year Period that Will Reach the Paris Agreement Limit’, *Nature Climate Change* (2025) online first, 2–3.

21 International Energy Agency, ‘World Energy Investment 2024’, 12, 88, 91.

22 Ibid., 22.

23 Urgewald, ‘Investing in Climate Chaos 2024: Institutional Investors $4.3 Trillion Deep into the Fossil Fuel Industry’, 9 July 2024, 3.

24 Oliver Milman and Nina Lakhani, ‘Revealed: Wealthy Western Countries Lead in Global Oil and Gas Expansion’, *Guardian*, 24 July 2024.

25 Urgewald, ‘Investing in Climate’, 3.

26 Damien Gayle, ‘Six Big US Banks Quit Net Zero Alliance before Trump Inauguration’, *Guardian*, 8 January 2025. ‘We are going to use the word “commitment” much more reservedly in the future, clearly differentiating between aspirations we are actively striving toward and binding commitments.’ JPMorgan Chase & Co., ‘Powering Growth with Curiosity and Heart: Annual Report 2023’, 27. JPMorgan also exited Climate Action 100+ and the Equator Principles, two other investor initiatives to create a semblance of green investment.

27 Jack Simpson, ‘BP “Abandoning Plan to Cut Oil Output” Angers Green Groups’, *Guardian*, 7 October 2024; Jillian Ambrose, Julia Kollewe and Kalyeena Makortoff, ‘“Very Concerning”: BP Dilutes Net Zero Targets as Global Retreat from Green Standards Gathers Pace’, *Guardian*, 13 October 2024.

28 Anders Opedal in Simon Jack, ‘Norwegian Oil Giant Cuts Green Investment in Half’, BBC, 6 February 2025.

29 *Guardian*, ‘“Climate Bomb” Warning over $200bn Wave of New Gas Projects’, 5 December 2024.

30 International Energy Agency, ‘World Energy’, 109–10; Global Energy Monitor, CREA, E3G et al., ‘Boom and Bust Coal 2024: Tracking the Global Coal Plant Pipeline’, April 2024.

31 Qi Qin and Christine Shearer, ‘When Coal Won’t Step Aside: The Challenge of Scaling Clean Energy in China’, CREA and Global Energy Monitor, 13 February 2025.

32 Chris Rosslowe and Beatrice Petrovich, ‘European Electricity Review 2025’, EMBER, 23 January 2025. For an optimistic take on the global solar boom, see Femke J. M. M. Nijsse, Jean-Francois Mercure, Nadia Ameli et al., ‘The Momentum of the Solar Energy Transition’, *Nature Communications* (2023) 14: 1–10. On the non-existing wind boom, see Will Mathis and Josh Saul, ‘A Wind Power Crisis Is Holding Back the World’s Green Energy Goal’, *Bloomberg*, 23 October 2024.

33 European Commission, ‘EU Greenhouse Gas Emissions Fell by Over 8% in 2023, Driven by Impressive Growth in Renewable Energy’, 31 October 2024.

34 International Energy Agency, ‘CO_2 Emissions in 2023: A New Record High, But Is There Light at the End of the Tunnel?’, 1 March 2024; Zeke Hausfather and Pierre Friedlingstein, ‘Global CO_2 Emissions Will Reach New High in 2024 Despite Slower Growth’, *Carbon Brief*, 13 November 2024.

35 Lisa Friedman, Coral Davenport, Jonathan Swan and Maggie Haberman, ‘At a Dinner, Trump Assailed Climate Rules and Asked $1 Billion from Big Oil’, *New York Times*, 9 May 2024. On Hamm, see Andreas Malm and the Zetkin Collective, *White Skin, Black Fuel: On the Danger of Fossil Fascism* (London: Verso, 2021), 182–4, 195–7.

36 Lisa Friedman, ‘Oil Interests Gave More than $75 Million to Trump PACs, New Analysis Shows’, *New York Times*, 1 November 2024. The oil and gas industry was ‘outpaced only by conservative interest groups which themselves are heavily funded with oil and gas money’, ibid.

37 Dharna Noor, ‘Trump Vows to “Unleash” Oil and Gas Drilling as He Rolls Back Climate Rules’, *Guardian*, 21 January 2025.

38 The White House, ‘Declaring a National Energy Emergency’, 20 January 2025.

39 Rebecca F. Elliott, ‘Oil Companies Embrace Trump, but Not “Drill, Baby, Drill”’, *New York* Times, 27 January 2025; Noor, ‘Trump Vows’. Oil in Alaska ‘is, they say, bigger than Saudi Arabia or the same size, and pure, really good stuff’. Alex DeMarban, ‘Trump Told Elon Musk the Arctic National Wildlife Refuge Could Have More Oil Than Saudi Arabia. “There’s No Way”, an Expert Says’, *Anchorage Daily News*, 14 August 2024.

40 Matt McGrath, ‘Trump Vows to Leave Paris Climate Agreement and “Drill, Baby, Drill”’, BBC, 21 January 2025.

41 This was a fascinating exercise in energy terminology by fiat. ‘For the purpose of this order, the following definitions shall apply: (a) The term “energy” or “energy resources” means crude oil, natural gas, lease condensates, natural gas liquids, refined petroleum products, uranium, coal, biofuels, geothermal heat, the kinetic movement of flowing water, and critical minerals … (b) The term “production” means the extraction or creation of energy. (c) The term “transportation” means the physical movement of energy, including through, but not limited to, pipelines.’ The White House, ‘Declaring a National’.

42 Noor, ‘Trump Vows’; Navin Singh Khadka, ‘How Trump’s “Drill, Baby, Drill” Pledge Is Affecting Other Countries’, BBC, 16 February 2024.

43 Agencies, ‘Hottest January on Record Mystifies Climate Scientists’, *Guardian*, 6 February 2025; Richard P. Allan, ‘Record January Heat Suggests La Niña May Be Losing Its Ability to Keep Global Warming In Check’, *The Conversation*, 7 February 2025.

44 Tim Dunn, CEO of CrownQuest Operating, quoted in Friedman, ‘Oil Interests’; J. D. Vance in Lisa Friedman, ‘J. D. Vance Is an Oil Booster and Doubter of Human-Caused Climate Change’, *New York Times*, 15 July 2024.

1. The Battle of Sainte-Soline

1 For good reason, as it would turn out: the French government in general and the interior minister, Gérald Darmanin, specifically had prepared for an assault on the demonstrators: see Gaspard d’Allens, ‘Mégabassines: Comment le gouvernment a préparé l’opinion à un mort’, *Reporterre*, 29 March 2023.

2 This account is based on observations by Malm; Jana Tsoneva, ‘No Bassaran: (Battle)Field Notes about a Few Revolutionary Days in France’, *Cross-Border Talks*, 6 April 2023 (originally published as ‘No bassaran: belezhki varhu nyakolko revolyutsionni dni vav Frantsia’, *Koi-bg*, 23 March 2023).

3 Figures for the years 2013–23: European Environment Agency, ‘Global and European Temperatures’, 26 June 2024.

4 Kumar Puran Tripathy and Ashok Kumar Mishra, ‘How Unusual Is the 2022 European Compound Drought and Heatwave Event?’, *Geophysical Research Letters* (2023) 50: 1–

12; Rémi Barroux and Gilles Rof, ‘Exceptional Winter Drought Puts French Authorities on Alert’, *Le Monde*, 23 February 2023.

5 On the reservoirs in Spain, see François Musseau, ‘Ressources en eau: L’Espagne envisage de vivre sans retenues’, *Liberation*, 26 March 2023.

6 The *mégabassines* issue first received informed treatment in Anglophone news media in Catherine Porter, ‘French Police Guard Water as Seasonal Drought Intensifies’, *New York Times*, 27 November 2022.

7 Much of this export – from fields irrigated by the *mégabassines* in Deux-Sèvres, their heartland – went through the port of La Rochelle, the target of another mass action and the scene of a somewhat less spectacular battle in July 2024.

8 This account rests on observations by Malm and discussions with numerous participants in the struggles against the *mégabassines*. The French coverage of this issue has become enormous. For just one piece on an emblematic species endangered by the projects – the little bustard – from the prime source of radical ecological reporting, see Léa Guedj, ‘L’outarde, l’oiseau “péteur” devenu totem des antibassines’, *Reporterre*, 21 August 2024.

9 ZAD for ‘zone à défendre’ or ‘zone to defend’. For an account in English, see Mauvaise Troupe Collective, *The ZAD and NoTAV: Territorial Struggles and the Making of a New Political Intelligence* (London: Verso, 2018).

10 This qualitative leap for the European climate movement was noted in Joost de Moor, ‘How Climate Activists Finally Seized the Issue of Adaptation in 2023’, *The Conversation*, 31 January 2024. This is not to say that Les Soulèvements de la Terre gave up on the classic struggle for mitigation; besides the resistance against the *mégabassines*, there were, for instance, the sensational sabotage actions against the Lafarge cement company and the campaign against the A69 highway.

11 For one account of these early phases of the struggle, written by the movement itself, see Les Soulèvements de la Terre, ‘To Those Who Marched at Sainte-Soline’, *Ill Will*, 24 April 2023.

12 On the bustard, see Guedj, ‘L’outarde, l’oiseau’.

13 Cf. the account by Kristin Ross, ‘The War of the Worlds’, *New York Review of Books*, 13 August 2023.

14 A meticulous investigation of the shooting of Serge Duteuil-Graziani, the worst-injured militant, was published by *Le Monde*, ‘How a French Demonstrator Ended Up in a Coma at Water Reservoir Protest’, YouTube, 6 April 2023. A full, detailed report of the repression at Sainte-Soline is Ligue des Droits de l’Homme, Observatoire Poitou-Charentes des Libertés Publiques, Observatoire Parisien des Libertés Publiques et al., ‘Sainte-Soline 24–26 mars 2023: Empêcher l’accès à la bassine quel qu’en soit le coût humain’, July 2023.

15 On maladaptation, see for example, A. K. Magnan, E. L. F. Schipper, M. Burkett et al. ‘Addressing the Risk of Maladaptation to Climate Change’, *WIREs Climate Change* (2016): 646–65; Lisa Schipper, Morgan Scoville-Simonds, Katharine Vincent and Siri Eriksen, ‘Why Avoiding Climate Change “Maladaptation” Is Vital’, *Carbon Brief*, 10 February 2021.

16 Ebba Brink, Ana Maria Vargas Falla and Emily Boyd, ‘Weapons of the Vulnerable? A Review of Popular Resistance to Climate Adaptation’, *Global Environmental Change* (2023) 80: 1–19.

17 France 24, ‘La justice française interdit quatre “mégabassines” dont celle de Sainte-Soline’, 18 December 2024.

18 Vincent Lucchese, ‘Mégabassines: pourquoi la justice n’écoute pas la science’, *Reporterre*, 20 December 2024.

2. The Rise of Muscular Adaptationism

1 Romain Felli, *The Great Adaptation: Climate, Capitalism and Catastrophe* (London: Verso, 2021 [2016]).
2 Ibid., for example, 28, 44–5, 51–9, 81–4, 156–8.
3 Ibid., 39–40.
4 Jesse H. Ausubel, 'Does Climate Still Matter?' (1991) 350: 649. Ironically, Ausubel borrowed the quoted phrase from William Nordhaus. On Ausubel's biography and influence, see The Rockefeller University, 'Jesse H. Ausubel', 2024.
5 Ibid.
6 Ibid.
7 Ibid., 649–51.
8 Ibid., 652.
9 United Nations, 'United Nations Framework Convention on Climate Change', 1992, for example, 4, 5.
10 Ibid., 4. Cf. for example, Mark Pelling, *Adaptation to Climate Change: From Resilience to Transformation* (Abingdon: Routledge, 2011), 8.
11 For a detailed chronicle of the ascent of adaptation during these years, see Mizan R. Khan and J. Timmons Roberts, 'Adaptation and International Climate Policy', *WIREs Climate Change* (2013) 4: 171–89; and for Paris onwards, Åsa Persson, 'Global Adaptation Governance: An Emerging but Contested Domain', *WIREs Climate Change* (2019) 10: 1–18.
12 For one recent standard account, see Lisa Dale, *Climate Change Adaptation* (New York: Columbia University Press, 2022), 1–2, 13.
13 *Economist*, 'Goodbye 1.5°C', 3 November 2022.
14 *DW*, 'Germany Needs Better Climate Policy, Merkel Says', 18 July 2021.
15 This included Annalena Baerbock, at that point the candidate for chancellor from the Greens, later the foreign minister of Germany: see, for example, Melissa Eddy and Steven Erlanger, 'Floods Thrust Climate Change to Center of German Campaign as Toll Mounts', *New York Times*, 17 July 2021. Talk about mitigation was not entirely absent in the wake of the floods, but the focus shifted towards adaptation.
16 Edgar Meza and Benjamin Wehrmann, 'Mass Flooding in Southern Germany Prompts Calls for Better Climate Adaptation and Civil Protection', *Clean Energy Wire*, 3 June 2024.
17 Jon Henley, 'Macron Vows to Rebuild and Replant by "Different Rules" after French Fires', *Guardian*, 20 July 2022.
18 Associated Press, 'Houses Washed Away after Storm Fiona as Canada Sends in Military for Cleanup', *Guardian*, 25 September 2022; Leyland Cecco, 'Canada Battles Hundreds of Wildfires as Smoke Still Chokes Major Cities', *Guardian*, 8 June 2023.
19 See, for example, Leyland Cecco, 'Canada Is Proposing to Lead on Climate – but It's Doubling Down on Oil', *Guardian*, 25 July 2024.
20 Justin McCurry, 'South Korea Floods: President Urges Climate Crisis Action as Death Toll Hits 40', *Guardian*, 17 July 2023.
21 Raphal Rashid, 'South Korea Accused of Paying Lip Service to Climate Action after Deadly Floods', *Guardian*, 20 July 2023.
22 Christopher Mims, 'How Better Tech Could Save Lives in a World of Bigger, Faster, More Devastating Fires', *Wall Street Journal*, 2 September 2023.
23 See, for example, William R. Travis, Joel B. Smith and Gary W. Yohe, 'Moving Toward 1.5°C of Warming: Implications for Climate Adaptation Strategies', *Current Opinion in Environmental Sustainability* (2018) 31: 146–52; Tabea K. Lissner, Tessa Möller,

Martina Angela Caretta and Aditi Mukherji, ‘Effectiveness of Water-Related Adaptation Decreases with Increasing Warming’, *One Earth* (2024) 7: 444–54.

24 Lissner et al., ‘Effectiveness of Water-Related’, 448. On non-linear declines, cf. 449; Travis et al., ‘Moving Toward’, 146, 148.

25 Laurie Laybourne, Henry Throp and Suzannah Sherman, ‘1.5°C – Dead or Alive? The Risks to Transformational Change from Reaching and Breaching the Paris Agreement Goal’, The Institute for Public Policy Research and Chatham House, February 2023, 5; cf. for example, 16–17; Laurie Laybourn and James Dyke, ‘A “Doom Loop” of Climate Change and Geopolitical Instability Is Beginning’, *The Conversation*, 9 December 2024. A similar loop theory is presented in Joel Milward-Hopkins, ‘Why the Impacts of Climate Change May Make Us Less Likely to Reduce Emissions’, *Global Sustainability* (2022) 5: 1–5.

3. Let Them Build Sea Walls

1 P. M. Kelly and W. N. Adger, ‘Theory and Practice in Assessing Vulnerability to Climate Change and Facilitating Adaptation’, *Climatic Change* (2000) 47: 328.

2 Ibid., 328–9; and for some other influential analyses from the early century, see W. Neil Adger, Jouni Paavola, Saleemul Huq and M. J. Mace, *Fairness in Adaptation to Climate Change* (Cambridge, MA: MIT Press, 2006); James D. Ford, E. C. H. Keskitalo, Tanya Smith et al., ‘Case Study and Analogue Methodologies in Climate Change Vulnerability Research’, *WIREs Climate Change* (2010) 1: 374–92. For an attempt to theorise vulnerability to climate change, see also Andreas Malm, ‘The Dialectics of Disaster: Considerations on Hazards and Vulnerability in the Age of Climate Breakdown, with a Brief Case Study of Khuzestan’, *Jàmbá: Journal of Disaster Risk Studies* (2023) 15: 1–9.

3 Dale, *Climate Change*, 13.

4 This draws on Andreas Malm and Shora Esmailian, ‘Ways In and Out of Vulnerability to Climate Change: Abandoning the Mubarak Project in the Northern Nile Delta, Egypt’, *Antipode* (2013) 45: 475–6, 486; for further references, see this paper.

5 For the latter, and further references, see ibid., 477–9; Andreas Malm, ‘Sea Wall Politics: Uneven and Combined Protection of the Nile Delta Coastline in the Face of Sea Level Rise’, *Critical Sociology* (2012) 39: 810–12.

6 Susmita Dasgupta, Benoit Laplante, Craig Meisner et al., ‘The Impact of Sea Level Rise on Developing Countries: A Comparative Analysis’, *Climatic Change* (2009) 93: 387. A higher estimate – one third for one metre – is reported in Mohamed E. Hereher, ‘Vulnerability of the Nile Delta to Sea Level Rise: An Assessment Using Remote Sensing’, *Geomatics, Natural Hazards and Risk* (2010) 1: 315–21.

7 Dasgupta et al., ‘The Impact of Sea’. Egypt thus ranks first in terms of agricultural land at risk, but second in terms of population at risk and third in terms of share of GDP under threat. Ibid. For more recent surveys of the vulnerability of the delta, see Khaled Abubakr Ali Abutaleb, Asmaa Hassan El-Sayed Mohammed and Mahmoud H. Mohamed Ahmed, ‘Climate Change Impacts, Vulnerabilities and Adaption [*sic*] Measures for Egypt’s Nile Delta’, *Earth Systems and Environment* (2018) 2: 183–92; Mohamed A. S. Abdel Monem and Biljana Radojevic, ‘Agricultural Production in Egypt: Assessing Vulnerability and Enhancing Adaptive Capacity and Resilience to Climate Change’, in El-Sayed Ewis Omran and Abdelazim M. Negm (eds), *Climate Change Impacts on Agriculture and Food Security in Egypt: Land and Water Resources*

– *Smart Farming – Livestock, Fishery, and Aquaculture* (Cham: Springer, 2020), 205–22; Dalia M. Gouda, 'Climate Change, Agriculture and Rural Communities' Vulnerability in the Nile Delta', in ibid., 525–76; Asaad M. Armanuos, Mohamed Samir Taha and Bakenaz A. Zeidan, 'Impact of Climate Changes on Seawater Intrusion in the Nile Delta Aquifer (Egypt)', in Shakir Ali and Abdelazim Negm (eds), *Groundwater Quality and Geochemistry in Arid and Semi-Arid Regions* (Cham: Springer, 2024), 97–163.

8 Drawing on Malm and Esmailian, 'Ways In', 481–2. The pools of salt are known as *sabkha* and used for extracting table salt: an adaptive practice of commodity production that would appeal to neoliberal advocates of adaptation. Mohamed E. Hereher, 'Coastal Vulnerability Assessment for Egypt's Mediterranean Coast', *Geomatics, Natural Hazards and Risk* (2015) 6: 353.

9 Hazem S. Kassem, Abdel Raouf Suleiman Bello, Bader M. Alotaibi et al., 'Climate Change Adaptation in the Delta Nile [*sic*] Region of Egypt: Implications for Agricultural Extension', *Sustainability* (2019) 11: 9. Cf. Silvia Torresan, Elisa Furlan, Andrea Critto et al., 'Egypt's Coastal Vulnerability to Sea-Level Rise and Storm Surges: Present and Future Conditions', *Integrated Environmental Assessment and Management* (2020) 16: 768.

10 Malm and Esmailian, 'Ways In', 482–3; Kassem et al., 'Climate Change', 11.

11 For further details, see Malm and Esmailian, 'Ways In'. For similar processes playing out in the lakes of the northern delta, see Andreas Malm and Shora Esmailian, 'Doubly Dispossessed by Accumulation: Egyptian Fishing Communities between Enclosed Lakes and a Rising Sea', *Review of African Political Economy* (2012) 39: 408–26.

12 For details, see Malm, 'Sea Wall'; and cf. for example, Hereher, 'Coastal Vulnerability', 353.

13 Cf. Andrea J. Nightingale, Noémi Gonda and Siri H. Eriksen, 'Affective Adaptation = Effective Transformation? Shifting the Politics of Climate Change Adaptation and Transformation from the Status Quo', *WIREs Climate Change* (2022) 13: 2.

14 Matthew Thomas Clement, '"Let Them Build Sea Walls": Ecological Crisis, Economic Crisis and the Political Economic Opportunity Structure', *Critical Sociology* (2011) 37: 447–63; and further Malm, 'Sea Wall'.

15 United Nations Development Programme, *Human Development Report 2007/2008: Fighting Climate Change. Human Solidarity in a Divided World*, 2007, 166.

16 For an excellent theorisation, see Kai Heron, 'Capitalist Catastrophism and Eco-Apartheid', *Geoforum* (2024) 153: 1–10.

4. Revolutionary Adaptation?

1 Michael Cote, ‘Egypt Is Extremely Vulnerable to Climate Change: Could a New Government Help the Country Adapt?’, *Good*, 6 February 2011.

2 On the cooperatives, see, for example, Malm and Esmailian, ‘Ways In’, 488; Gouda, ‘Climate Change’, 547.

3 Cf. Malm, ‘Sea Wall’, 825.

4 For example, Dale, *Climate Change*, 14–15, 136.

5 Michael Mikulewicz, ‘Politicizing Vulnerability and Adaptation: On the Need to Democratize Local Responses to Climate Impacts in Developing Countries’, *Climate and Development* (2018) 10: 18–34; Leigh Johnson, Michael Mikulewicz, Patrick Bigger et al., ‘Intervention: The Invisible Labor of Climate Change Adaptation’, *Global Environmental Change* (2023) 83: 1–7.

6 Malmö Stad, ‘Skyfallsanpassning’, 17 May 2024.

7 Salvatore Paolo De Rosa, Joost de Moor and Marwa Dabaieh, ‘Vulnerability and Activism in Urban Climate Politics: An Actor-Centered Approach to Transformational Adaptation in Malmö (Sweden)’, *Cities* (2022) 130: 5.

8 See further ibid.

9 For one manifesto along these lines by an influential figure in the European climate movement, of whom more below, see Tadzio Müller, ‘A (Sort of a) Manifesto for the #Justcollapse Left’, *Friedliche Sabotage*, 1 June 2024.

10 Elisa Savelli, Maurizio Mazzoleni, Giuliano Di Baldassarre et al., ‘Urban Water Crisis Driven by Elites’ Unsustainable Consumption’, *Nature Sustainability* (2023) 6: 929–40.

11 See, for example, Mercely Thomas, ‘Climate Activists Fill Golf Holes with Cement after Water Ban Exemption’, BBC, 13 August 2022; Marjorie Cessac, ‘Golf Courses Squeezed by Drought and Climate Activists’, *Le Monde*, 4 July 2023.

12 Ben Wisner, Piers Blaikie, Terry Cannon and Ian Davis, *At Risk: Natural Hazards, People’s Vulnerability and Disasters* (London: Routledge, 2005), 91; Ford et al., ‘Case Study’, 383 (emphasis added). Or, if ‘it is not so much the droughts or floods that are alarming, but people’s vulnerability to the consequences associated with them’, then eradication of the vulnerability would silence the alarm. Jesse C. Ribot, Adil Najam and Gabrille Watson, ‘Climate Variation, Vulnerability and Sustainable Development in the Semi-Arid Tropics’, in E. Lisa Schipper and Ian Burton (eds), *The Earthscan Reader on Adaptation to Climate Change* (London: Earthscan, 2009 [1996]), 133. The mirror image is arguably also found in the programme for ‘disaster communism’, as it claims that scarcity in a moment of climate disaster is manufactured by the capitalist social relations within which it plays out. ‘In a conventional and narrowly economic sense, scarcity exists in these situations. But this scarcity is challenged by an abundance of social links’, which, if the disaster community only organises in a properly communist fashion, can break out from the tightening screws and institute actual abundance – even as the disaster is ongoing. ‘We should not be too hasty or certain in associating ecological crisis with increased scarcity.’ Out of the Woods Collective, ‘Disaster Communism: The Uses of Disaster’, in *Hope against Hope: Writings on Ecological Crisis* (New York: Common Notions, 2020), 238. The non-materialist fallacy here is that abundance can be stretched out if only people treat each other right, regardless of whether the goods on offer from nature are being reduced to a trickle. The notion of disaster communism is built on the idea that ‘abundance’ emerges *in the moment of*

disaster, which seems rather a stretch, for the future in particular. See further ibid., for example, 239–40. But, granted, the Out of the Woods Collective pairs this programme with calls for abolishing fossil fuels.

13 See further Andreas Malm, ‘Tahrir Submerged? Five Theses on Revolution in the Era of Climate Change’, *Capitalism Nature Socialism* (2014) 25: 9–10.

14 For example, Farnaz Fassihi, ‘“I Am Thirsty!” Water Shortages Compound Iran’s Problems’, *New York Times*, 21 July 2021. For a somewhat fuller account, see Malm, ‘Dialectics of Disaster’, 5–10.

15 See, for example, Omid Shokri, ‘Iran Faces Its Driest Summer in Fifty Years’, *Atlantic Council*, 7 July 2021; Nasser Karami, ‘The Grapes of Khuzestan’s Wrath’, *Atlantic Council*, 30 July 2021; and for more on the background, Malm, ‘Dialectics of Disaster’, 5–10.

16 More precisely, the third largest corporation in the world measured in the greenhouse gas emissions its products generated, as of 2015. Paul Griffin, ‘The Carbon Majors Database: CDP Carbon Majors Report 2017’, CDP Worldwide and Climate Accountability Institute, July 2017, 10.

17 Climate Central, ‘Analysis: Valencia Floods Fueled by Ocean Warming in the Tropical Atlantic Linked to Climate Change’, 31 October 2024; World Weather Attribution, ‘Extreme Downpours Increasing in Southeastern Spain as Fossil Fuel Emissions Heat the Climate’, 4 November 2024.

18 Jeanne Cassard, ‘Inondations en Espagne: les lourdes erreurs de la droite au pouivor’, *Reporterre*, 5 November 2024.

19 Al Jazeera, ‘Thousands Protest in Spain’s Valencia Over Handling of Deadly Floods’, 9 November 2024; BBC News Mundo, ‘“Nosotros estamos manchados de barro, ustedes de sangre”: la masiva manifestación por la repuesta de las autoridades al desastre de la DANA en Valencia’, 10 November 2024.

20 We owe this observation to Léa Guedj.

21 Manuel Planelles, ‘A Report Places Spain’s Repsol among the 50 Largest Global Emitters of CO_2 in the Last 170 Years’, *El País*, 4 April 2024.

22 Marianna Parraga, ‘Spain’s Repsol Receives US License for Venezuela Oil, Gas Projects – Sources’, *Reuters*, 23 May 2024.

23 Louis-Maxence Delaporte, Henri Her and Bastien Gebel, ‘Assessment of Repsol’s Climate Strategy’, *Reclaim Finance*, April 2024.

24 *Guardian*, ‘Spain Introduces Paid Climate Leave after Deadly Floods’, 29 November 2024.

25 Lea Berrang-Ford, A. R. Siders, Alexandra Lesnikowski et al., ‘A Systematic Global Stocktake of Evidence on Human Adaptation to Climate Change’, *Nature Climate Change* (2021) 11: 989–98.

5. Bring out the Snow Cannons

1 John C. Moore, Rupert Gladstone, Thomas Zwinger and Michael Wolovick, ‘Geoengineer Polar Glaciers to Slow Sea-Level Rise’, *Nature* (2018) 555: 304.

2 Ibid.

3 See, for example, Arctic Centre, University of Lapland, ‘Preventing Ice Sheet Collapse by Seabed Anchored Curtains in Greenland Taking Steps Forward’, 26 October 2022; Douglas MacAyeal, John Moore, Kenneth Mankoff et al., ‘Glacial Climate Intervention: A Research Vision’, Climate Systems Engineering Initiative, University of Chicago,

2024, 7, 12; Robin McKie, ‘How Do You Stop a Glacier from Melting? Simple – Put Up an Underwater Curtain’, *Guardian*, 4 February 2024; Fred Pearce, ‘As “Doomsday” Glacier Melts, Can an Artificial Barrier Save It?’, *Yale Environment 360*, 26 August 2024.

4 Pearce, ‘As “Doomsday”’.

5 Jon Gertner, ‘Can $500 Million Save this Glacier?’, *New York Times*, 6 January 2024.

6 John C. Moore, Ilona Mettiäinen, Michael Wolovick et al., ‘Targeted Geoengineering: Local Interventions with Global Implications’, *Global Policy* (2021) 12: 111.

7 For a survey, see Andrew Lockley (about whom more below), Michael Wolovick, Bowie Keefer et al., ‘Glacier Geoengineering to Address Sea-Level Rise: A Geotechnical Approach’, *Advances in Climate Change Research* (2020) 11: 401–14. For the glass bubbles, see Rachel Riederer, ‘A Heat Shield for the Most Important Ice on Earth’, *New Yorker*, 25 April 2023. Cloud seeding over Antarctica was proposed in Erik J. L. Larson, Karen H. Rosenlof and Ru-Shan Gao, ‘Increasing Antarctic Ice Mass to Help Offset Sea Level Rise’, *Atmosphere* (2023) 14: 1–9.

8 Steven J. Desch, Nathan Smith, Christopher Groppi et al., ‘Arctic Ice Management’, *Earth’s Future* (2017) 5: 107–27.

9 Jacob Pantling, Katherine Cartlidge, M. Grae Worster and Shaun D. Fitzgerald, ‘Modelling the Responses of an Ice Surface to a Water Flow in the Context of Ice Thickening’, *International Journal of Thermal Sciences* (2024) 204: 1.

10 Mark Poynting, ‘Climate Change: The “Insane” Plan to Save the Arctic’s Sea-Ice’, BBC, 16 March 2024; Senay Boztas, ‘Pumped Up: Will a Dutch Startup’s Plan to Restore Arctic Sea-Ice Work?’, *Guardian*, 27 February 2024.

11 Cf. Gertner, ‘Can $500’.

12 Desch et al., ‘Arctic Ice’, 119.

13 Ibid., 120.

14 See Lockley et al., ‘Glacier Geoengineering’, for example, 406, 410.

15 This is recognised sotto voce in MacAyeal et al., ‘Glacial Climate’, 15.

16 This is recognised in Moore et al., ‘Targeted Geoengineering’, 111.

17 Jacob Pantling, ‘Scientists Test “Insane” Plan to Slow Ice Melt in Canadian Arctic’, *The Energy Mix*, 8 April 2024.

18 MacAyeal et al., ‘Glacial Climate’, 15.

19 On the failure to bend the curve, see Lorenzo Zampieri and Helge F. Goessling, ‘Sea Ice Targeted Geoengineering Can Delay Arctic Sea Ice Decline but not Global Warming’, *Earth’s Future* (2019) 7: 1296–1306.

20 Moore et al., ‘Targeted Geoengineering’, 114.

21 Cf. ibid., 113–16. See also Patrick Flamm and Akiho Shibata, ‘“Ice Sheet Conservation” and International Discord: Governing (Potential) Glacial Geoengineering in Antarctica’, *International Affairs* (2025) 101: 309–320; Nikolaj Kornbech, Olaf Corry and Duncan McLaren, ‘Securing the “Great White Shield”? Climate Change, Arctic Security and the Geopolitics of Solar Geoengineering’, *Cooperation and Conflict* (2024), online first.

6. Lamps over the Rainforest

1 Xueyuan Gao, Shunlin Liang, Dongdong Wang et al., ‘Exploration of a Novel Geoengineering Solution: Lighting up Tropical Forests at Night’, *Earth System Dynamics* (2022) 13: 219 (‘greenhouse gas emissions’ are here abbreviated GHG in the original).

2 Ibid., 224 (here correcting the typo ‘along’ in the original). The fact that the team labelled this technology for carbon dioxide removal a form of ‘geoengineering’ speaks to the enduring conflation of the two categories.

3 Ibid., 226. The model runs also suggested that local temperatures and precipitation would spike. Ibid., 222. This study is remarkable for not engaging with extant research on how artificial light at night disrupts vegetation and the ecosystems centred on it. In environments where the light is constant – cities, that is – trees have been shown to have developed such thick leaves that insects cannot eat them, with knock-on effects higher up the food chain: fewer insects, fewer birds, and so on. Yu Cao, Shuang Zhang and Ke-Ming Ma, ‘Artificial Light at Night Decreases Leaf Herbivory in Typical Urban Areas’, *Frontiers in Plant Science* (2024) 15: 1–9. Hanging lamps on the rainforest amount to throwing a bomb into it and waiting to see how the organisms that live there react.

4 Gao et al., ‘Exploration of a Novel’, 226–7.

5 Ibid., 225.

6 Susan Solomon, Gian-Kasper Plattner, Reto Knutti and Pierre Friedlingstein, ‘Irreversible Climate Change Due to Carbon Dioxide Emissions’, *PNAS* (2009) 106: 1704–9 (note that the ‘irreversibility’ demonstrated here is based on natural processes of carbon dioxide removal; artificial removal does not figure in this classic paper); M. Eby, K. Zickfeld, A. Montenegro et al., ‘Lifetime of Anthropogenic Climate Change: Millennial Time Scales of Potential CO_2 and Surface Temperature Perturbations’, *Journal of Climate* (2009) 22: 2501–11; Kirsten Zickfeld, Michael Eby, Andrew J. Weaver et al., ‘Long-Term Climate Change Commitment and Reversibility: An EMIC Intercomparison’, *Journal of Climate* (2013) 26: 5782–809; David Archer, *The Long Thaw: How Humans Are Changing the Next 100,000 Years of Earth’s Climate* (Princeton: Princeton University Press, 2009).

7 But this only holds for emissions of carbon dioxide – ending those of short-lived greenhouse gases, notably methane, would in fact help temperatures drop somewhat. See, for example, Ilissa B. Ocko, Tianyi Sun, Drew Shindell et al., ‘Acting Rapidly to Deploy Readily Available Methane Mitigation Measures by Sector Can Immediately Slow Global Warming’, *Environmental Research Letters* (2021) 16: 1–11.

8 Wake Smith, *Pandora’s Toolbox: The Hopes and Hazards of Climate Intervention* (Cambridge: Cambridge University Press, 2022), 24. For other elaborations of the metaphor, see Archer, *The Long*, 16–19, 25; Sabine Fuss, Chris D. Jones, Ingrid Schulte and Naomi Vaughan, ‘Cleaning Up After Ourselves: The Role of Carbon Dioxide Removal’, *Frontiers for Young Minds* (2024) 12: 1345470; Sophie Guy, Yoshihisa Kashima, Iain Walker and Saffron O’Neill, ‘Comparing the Atmosphere to a Bathtub: Effectiveness of Analogy for Reasoning about Accumulation’, *Climatic Change* (2013) 121: 579–94; Varun Dutt and Cleotilde Gonzalez. ‘Human Control of Climate Change’, *Climatic Change* (2012) 111: 497–518.

9 Smith, *Pandora’s Toolbox*, 24, 151 (and cf. for example, 100).

10 NOAA, ‘During a Year of Extremes, Carbon Dioxide Levels Surge Faster than Ever’, 6 June 2024. The exact seasonal peak at Mauna Loa was 426.9 ppm.

11 J. Hansen, M. Sato, P. Kharecha et al., ‘Target Atmospheric CO_2: Where Should Humanity Aim?’, *Open Atmospheric Science Journal* (2008) 2: 217–31.

12 Bill McKibben, ‘Remember This: 350 Parts Per Million’, *Washington Post*, 28 December 2007. On McKibben and the divestment campaigns, see Malm and Carton, *Overshoot*, for example, 103–4.

13 Casey Crownhart, ‘The Hope and Hype of Seaweed Farming for Carbon Removal’, *MIT Technology Review*, 22 June 2023.

14 Smith, *Pandora’s Toolbox*, 151.

15 cur8.earth.
16 Negative Emissions Platform, ‘Carbon Removal Summit: The Business of CDR’, YouTube, 14 June 2023.
17 Shashank Samala in Heirloom, ‘Heirloom Unveils America’s First Commercial Direct Air Capture Facility’, 9 November 2023.
18 Quoted in Corbin Hiar and Alex Nieves, ‘Small Step for Climate, Giant Leap for DAC’, *Politico*, 11 September 2023.
19 280.earth; Michelle Ma and Biz Carson, ‘Sergey Brin-Backed Startup Leverages Data Centres to Capture Carbon’, *Bloomberg*, 5 February 2024. On these companies, see further below.
20 Jacob Bronsther, ‘Carbon Time Machine’, *The Washington Quarterly* (2023) 46: 27; Lara Williams, ‘Carbon Removal Is Where Green Investment Should Go’, *Bloomberg*, 27 January 2023.
21 ETH Foundation, ‘Success through Perseverance’, 1 June 2021. Climeworks seems to have abandoned this motto since then, perhaps recognising some of the problems with it. On this company, see below.
22 Graciela Chichilnisky and Peter Bal, *Reversing Climate Change: How Carbon Removals Can Resolve Climate Change and Fix the Economy* (Singapore: World Scientific Publishing, 2019), 279.
23 Lower Carbon Capital, 2024.
24 UNDO, ‘About Us’, 2024.
25 For just two more examples, see Clive Thompson, ‘Can Vacuuming Carbon Dioxide Out of the Air Reverse Climate Change?’, *Bulletin of the Atomic Scientists*, 8 November 2021; *New Scientist*, ‘We Need to Go beyond Net Zero to Reverse Catastrophic Climate Damage’, 7 June 2023.
26 Negar Vakilifard, Richard G. Williams, Philip B. Holden et al., ‘Impact of Negative and Positive CO_2 Emissions on Global Warming Metrics Using an Ensemble of Earth System Model Simulations’, *Biogeosciences* (2022) 19: 4250.
27 Peter Fiekowsky, *Climate Restoration: The Only Future That Will Sustain the Human Race* (Irvington: Rivertown Books, 2022), 22; for his foundation, see Foundation for Climate Restoration, ‘Philosophy’, 2023.
28 Fiekowsky, *Climate Restoration*, 30.
29 Gideon Futterman, Rowan Williams, James E. Hansen et al., ‘Hitting Net Zero Is Not Enough – We Must Restore the Climate’, *Guardian*, 13 November 2020.
30 For example, Andrew Dana Hudson, ‘Zero Emissions Isn’t Enough. We Need Climate Repair’, *Jacobin*, 19 August 2022; Duncan McLaren, ‘In a Broken World: Towards an Ethics of Repair in the Anthropocene’, *Anthropocene Review* (2018) 5: 136–54; Robinson Meyer, ‘Why a Political Philosopher Is Thinking about Carbon Removal’, *The Atlantic*, 3 March 2021; cf. Olúfémi O. Táíwò, *Reconsidering Reparations* (Oxford: Oxford University Press, 2022); and see further Holly Jean Buck, *After Geoengineering: Climate Tragedy, Repair, and Restoration* (London: Verso, 2019); Holly Jean Buck, *Ending Fossil Fuels: Why Net Zero Is Not Enough* (London: Verso, 2021), 52–3.
31 See, for example, David Wallace-Wells, ‘Climate Reparations. A Trillion Tons of Carbon Hangs in the Air, Put There by the World’s Rich, an Existential Threat to Its Poor. Can We Remove It?’, *New York Magazine*, 1 November, 2021.
32 For this kind of planning, see further Malm and Carton, *Overshoot*.
33 Jesse Nusbaumer and Katsumi Matsumoto, ‘Climate and Carbon Cycle Changes under the Overshoot Scenario’, *Global and Planetary Change* (2008) 62: 164–72. This paper followed hot on the heels of Chris Huntingford and Jason Lowe, ‘“Overshoot” Scenarios

and Climate Change', *Science* (2007) 316: 829. On the latter, see Malm and Carton, *Overshoot*, 73–4, 296.

7. Breaks in the Time Machine

1 For classic statements on the linear relationship in general, see for example, Myles R. Allen, David J. Frame, Chris Huntingford et al., 'Warming Caused by Cumulative Carbon Emissions towards the Trillionth Tonne', *Nature* (2009) 458: 1163–6; H. Damon Matthews, Nathan P. Gillett, Peter A. Stott and Kirsten Zickfeld (2009), 'The Proportionality of Global Warming to Cumulative Carbon Emissions', *Nature* (2009) 459: 829–32. Plenty of uncertainties remain, including regarding climate sensitivity; most damaging to the linear relationship is the effect of positive feedback mechanisms to global warming, which threaten to destroy it. See below.

2 See further Malm and Carton, *Overshoot*.

3 James Hutton, 'Theory of the Earth; or an Investigation of the Laws Observable in the Composition, Dissolution, and Restoration of Land upon the Globe', *Transactions of the Royal Society in Edinburgh* (1788) 1: 209 (emphasis added). An excellent summary of Hutton's worldview and influence can be found in Trevor Palmer, *Perilous Planet Earth: Catastrophes and Catastrophism through the Ages* (Cambridge: Cambridge University Press, 2003), 14–22.

4 Hutton, 'Theory of the Earth', 212–86.

5 Ibid., 293.

6 Ibid., 217, 215; Stephen Jay Gould, *Time's Arrow, Time's Cycle: Myth and Metaphor in the Discovery of Geological Time* (Cambridge, MA: Harvard University Press, 2001 [1987]), 66.

7 Hutton, 'Theory of the Earth', 216, 273, 294; cf. Gould, *Time's Arrow*, 65; Palmer, *Perilous Planet*, 18.

8 Gould, *Time's Arrow*, 79–81, 85.

9 John Playfair quoted in ibid., 94. There is 'no occasion for having recourse to … any destructive accident in nature … in explaining that which actually appears'. Hutton, 'Theory of the Earth', 285.

10 Hutton to Watt in 1774, Watt to Hutton 1795, in Jean Jones, Hugh S. Torrents and Eric Robinson, 'The Correspondence between James Hutton (1726–1797) and James Watt (1736–1819) with Two Letters from Hutton to George Clerk-Maxwell (1715–1784): Part II', *Annals of Science* (1995) 52: 364, 380 (emphasis added). On Hutton's close relationship with Watt and verbal and practical encouragement of his engine, see further this article and its preceding part I in *Annals of Science* (1994) 51: 637–53.

11 Stephen Jay Gould, *The Structure of Evolutionary Theory* (Cambridge, MA: Harvard University Press, 2002), 484–92; Tony Hallam, *Catastrophes and Lesser Calamities: The Causes of Mass Extinctions* (Oxford: Oxford University Press, 2004), 8–13; Palmer, *Perilous Planet*, 23–35; Trevor Jackson, 'Revolution and Extinction: The Chrono-Economics of Capitalism', *Critical Historical Studies* (2022) 9: 283–306.

12 Quoted in Gould, *Time's Arrow*, 122.

13 Quoted in ibid., 108; see further, for example, 105, 123, 151; Gould, *The Structure*, 481; Palmer, *Perilous Planet*, 45–53.

14 Geoffrey C. Bowker, 'The Time of Computers: From Babbage and the 1830s to the Present', in William Aspray (ed.), *Historical Studies in Computing, Information and Society: Insights from the Flatiron Lectures* (Cham: Springer, 2020), 7. See further Hallam, *Catastrophes*, 13; Gould, *Time's Arrow*, 147–9.

15 Bowker, 'The Time', 7–8.

16 The slowness, of course, deviating from automated machinery. Gradualism – or 'uniformitarianism' – was, however, perfectly consonant with acceleration in the writings of Babbage: see ibid.

17 Lyell quoted in Brian P. Dolan, 'Representing Novelty: Charles Babbage, Charles Lyell, and Experiments in Early Victorian Geology', *History of Science* (1998) 36: 312. On the relation and mutual influences of the two men, as well as Babbage's own forays into geology, see further this paper; Carla Petrocelli, '"The Earth Calculus": Babbage, Tables, and the Calculating Machine in the Study of Geology', *Rendiconti Lincei: Scienze Fisiche e Naturali* (2021) 32: 245–55; Bowker, 'The Time'.

18 Quoted in Bowker, 'The Time', 8.

19 As noticed in ibid., 4–5, 13; and see further Andreas Malm, *Fossil Capital: The Rise of Steam Power and the Roots of Global Warming* (London: Verso, 2016).

20 Bowker, 'The Time', 12. For Babbage's place in the transition to steam, see further Malm, *Fossil Capital*. Of at least as great an importance was the ideological affinity between anti-catastrophist unitarianism and perpetual accumulation, in which things stay the same by constantly growing. Capitalist notions of time have no place for abrupt endings, be they revolutionary or catastrophic (or both). See further Jackson, 'Revolution and Extinction'.

21 As Gould himself noticed about his and Niles Eldredge's observations about how gradualism arose in Victorian Britain: 'We raised this point as sociological commentary about the *origin* of ideas, not as a scientific argument for the *validity* of the same ideas. An identification of cultural or ontogenetic sources says nothing about truth value, an issue that can only be settled by standard scientific procedures of observation, experiment and empirical test.' Gould, *The Structure*, 1018 (emphases in original).

22 Gould, *Structure*, for example, 969.

23 Charles Darwin, *The Origin of Species*, in Charles Darwin, *The Origin of Species* and *The Voyage of the Beagle* (London: Vintage, 2009 [1859]), 612; and see further Gould, *The Structure*, 143–55.

24 See Darwin, *The Origin*, for example, 689, 726, 899. The credo of *natura non facit saltum* stemmed from Leibniz; but for him, apparently, the absence of leaps was a truth from God's point of view, while for the human eye they seemed rather common. Emmanuel Barot, 'Review of *Sciences et dialectiques de la nature* by Lucien Sève (ed.) and *La nature dans la pensée dialectique* by Eftichos Bitsakis', *Historical Materialism* (2010) 18: 153. The credo was later taken up by Alfred Marshall as an expression of the truths of neoclassical economics, the epitome of bourgeois ideology: economic life is orderly and equilibrated and stably progressing. Geoffrey Fishburn, '*Natura Non Facit Saltum* in Alfred Marshall (and Charles Darwin)', *History of Economics Review* (2004) 40: 59–68. Events 'which are spasmodic, infrequent, and difficult of observation, are commonly reserved for special examination at a later stage', i.e. bracketed out of the picture. Marshall quoted in ibid., 61. This could be the credo for IAMs.

25 Palmer, *Perilous Earth*, 70–1.

26 See, for example, Darwin, *The Origin*, 672–7, 776–7; Palmer, *Perilous Earth*, 47; Gould, *Time's Arrow*, 133–4, 176; Gould, *The Structure*, 151–2, 756–9; Simon Conway Morris, 'Darwin's Dilemma: The Realities of the Cambrian Explosion', *Philosophical Transactions of the Royal Society of London B* (2006) 361: 1069–83 (and for the Cambrian explosion and Darwin's inability to come to terms with it, see further another masterpiece of Stephen Jay Gould, *Wonderful Life: The Burgess Shale and the Nature of History* [New York: W. W. Norton, 1989]).

27 Georg Wilhelm Friedrich Hegel, *The Science of Logic* (Cambridge: Cambridge University Press, 2010 [1816–32]), 289–91, 319–20 (quotation from 291).

28 Ibid., 321 (emphasis added). This remains a paradigmatic example – without reference to Hegel – in, for example, Ricard V. Solé, *Phase Transitions* (Princeton: Princeton University Press, 2011), xi, 44.

29 Although he does not speak specifically of CO and CO_2.

30 The meaning of *knotenlinie* in Hegel is a line with 'nodes' on it, like a knotted string, where each node marks the point of a leap. Water would then pass through a nodal line, on which 0°C and 100°C are the main nodes. The line is the progression of gradual change, the nodes the interruptions. We shall adapt this term and, so to speak, turn the line into a horizontal rather than a vertical one, as when one *crosses a line*, the line being a limit or boundary. This usage of the term is more in line (*sic*) with the object of interest – namely, the rise of temperatures towards certain limits. Put more simply, it makes better sense to refer to, for example, 1.5°C as a nodal *line* at which contradictions are intensified, rather than as a node and the temperature rise as a line. On the meaning of *knotenlinie* in Hegel, see Ulrich Ruschig, 'Logic and Chemistry in Hegel's Philosophy', *HYLE: International Journal for Philosophy of Chemistry* (2001) 7: 14, 18; David Gray Carlson, 'Hegel and the Becoming of Essence', *Cosmos and History: The Journal of Natural and Social Philosophy* (2007) 3: 281–2. With thanks to Henrike Kohpeiß.

31 On wet-bulb temperature and its relation to 1.5°C, see Malm and Carton, *Overshoot*, 42–4. The examples could be multiplied: 'Many plans flower when the total number of degree-days accumulated above a certain temperature has reached a critical threshold. The onset of and release from winter hibernation in mammals like bears occur when the accumulated level of certain compounds in the blood reaches a critical level. A few cloudy or cold days will not cause birds to migrate southward or leaves to fall from deciduous trees. In all these cases there is some physical transduction of external signals into stored chemical information that serves as a trigger for physiological and behavioural changes at critical thresholds.' Richard Lewontin, *The Triple Helix: Gene, Organism, and Environment* (Cambridge, MA: Harvard University Press, 2000), 61–2. Cf. Richard Levins and Richard Lewontin, *The Dialectical Biologist* (Cambridge, MA: Harvard University Press, 1985), 39.

32 Hegel, *The Science*, 322.

33 Karl Marx, *Capital: A Critique of Political Economy. Volume I* (London: Penguin, 1990 [1867]), 423–4. Cf. John Bellamy Foster, *The Return of Nature: Socialism and Ecology* (New York: Monthly Review Press, 2020), 241 (emphasis in original); and on this aspect of Marxian dialectics, see further the classic account of Bertell Ollman, *Dance of the Dialectic: Steps in Marx's Method* (Urbana: University of Illinois Press, 2003), for example, 16–20, 86.

34 Friedrich Engels, *Dialectics of Nature* (Moscow: Progress Publishers, 1986 [1872–82]), 63. See further 17, 62–8, 77, 252, 294, 300; Foster, *The Return*, 218–21, 239–42; Kaan Kangal, *Friedrich Engels and the* Dialectics of Nature (Cham: Palgrave MacMillan, 2020), 170–1.

35 Namely, through the work of the socialist chemist Carl Schorlemmer, precociously studying the chemistry of *amerikanische Steinöl* just discovered in Pennsylvania. For this in hindsight remarkable episode and Engels's absorption of it, see Sven-Eric Liedman, *The Game of Contradictions: The Philosophy of Friedrich Engels and Nineteenth-Century Science* (Chicago: Haymarket, 2023 [1983]), 351–61, 422–5. The case of the carbon compounds made their way from the oilfields of Pennsylvania via Schorlemmer and Engels into *Capital*.

36 Engels, *Dialectics of Nature*, 17, 62. The third law fused with a sometimes proposed fourth on 'the negation of the negation' and 'development through contradiction'.

Kangal, *Friedrich Engels*, 168; Kaan Kangal, 'Engels's Conception of Dialectics in the *Plan 1878* of *Dialectics of Nature*', in Kohei Saito (ed.), *Reexamining Engels' Legacy in the 21st Century* (Cham: Palgrave MacMillan, 2021), 79–80. On the spiral as form of development, cf. Cf. Scott Borchers, *Hegel's Logic and Global Climate Change*, PhD dissertation, Vanderbilt University, 2006, 56–7; Ollman, *Dance of the Dialectic*, for example, 141.

37 Cf. for example, Kangal, *Friedrich Engels*, 68; Barot, 'Review of *Sciences*', 147.

38 On this tradition, see Foster, *The Return*.

39 Ibid., 516. On Lewontin's Marxism, see Stuart A. Newman, 'Richard Lewontin (1929–2021): Evolutionary Biology's Great Disrupter', *Capitalism Nature Socialism* (2021) 32: 11–16.

40 Richard C. Lewontin, 'The Meaning of Stability', *Brookhaven Symposiums in Biology* (1969) 22: 13–24. On this as the paper introducing the theory of alternative stable states, see Robert M. May, 'Thresholds and Breakpoints in Ecosystems with a Multiplicity of Stable States', *Nature* (1977) 269: 471, 477; B. E. Beisner, D. T. Haylon and K. Cuddington, 'Alternative Stable States in Ecology', *Frontiers in Ecology and the Environment* (2003) 1: 376. On this same paper inaugurating post-1968 anti-gradualist natural science, see Marten Scheffer, *Critical Transitions in Nature and Society* (Princeton: Princeton University Press, 2009), 12–13.

41 Lewontin, 'The Meaning', 15, 21–22 (emphases removed from original). Cf. Scheffer, *Critical Transitions*, 14–18, 22, 29, 83. The ball is described in, for example, Beisner et al. 'Alternative Stable', 377, 379. Lewontin had insisted on the importance of historical sequence and order of events in a previous paper, 'The Principle of Historicity in Evolution', in Paul S. Moorhead and Martin M. Kaplan (eds), *Mathematical Challenges to the Neo-Darwinian Interpretation of Evolution* (New York: Alan R. Liss, 1967), 81–94.

42 For the theory in all its brilliance, see Niles Eldredge and Stephan Jay Gould, 'Punctuated Equilibria: An Alternative to Phyletic Gradualism', in Thomas J. M. Schopf (ed.), *Models in Paleobiology* (San Francisco: Freeman, Cooper & Co., 1972), 82–115; Stephen Jay Gould and Niles Eldredge, 'Punctuated Equilibrium Comes of Age', *Nature* (1993) 366: 223–7; Gould, *The Structure*, 745–1024.

43 Gould, *The Structure*, 952, 885.

44 Ibid., 929.

45 Stephen Jay Gould, 'The Episodic Nature of Evolutionary Change', in *The Panda's Thumb: More Reflections in Natural History* (New York: W. W. Norton, 1980), 184–5; Joshua M. Epstein, 'Modeling Civil Violence: An Agent-Based Computation Approach', *PNAS* (2002) 99: 7245. On Gould's Marxism, see, for example, Val Dusek, 'Stephen Jay Gould: Marxist as Biologist', *Rethinking Marxism* (2003) 15: 451–65; on Science for the People, Foster, *The Return*, 514–15.

46 Michael J. O'Brien, Sergi Valverde, Salva Duran-Nebrada et al., 'Punctuated Equilibrium at 50: Anything there for Evolutionary Anthropology? Yes; Definitely', *Evolutionary Anthropology* (2023), online first; Robert Repetto (ed.), *Punctuated Equilibrium and the Dynamics of US Environmental Policy* (New Haven: Yale University Press, 2006); Salva Duran-Nebreda, R. Alexander Bentley, Blai Vidiella et al., 'On the Multiscale Dynamics of Punctuated Equilibrium', *Trends in Ecology and Evolution* (2024) 39: 734–4.

47 See, for example, Per Bak and Kim Sneppen, 'Punctuated Equilibrium and Criticality in a Simple Model of Evolution', *Physical Review Letters* (1993) 71: 4083–6; Kim Sneppen, Per Bak, Henrik Flyvbjerg and Mogens H. Jensen (1995), 'Evolution as a Self-Organized Critical Phenomenon', *PNAS* (1995) 92: 5209–13; Per Bak, *How Nature*

Works: The Science of Self-Organized Criticality (Oxford: Oxford University Press, 1997); Per Bak and Stefan Boettcher, 'Self-Organized Criticality and Punctuated Equilibria', *Physica D* (1997) 107: 143–50. Dmitry Zhukov, 'How the Theory of Self-Organized Criticality Explains Punctuated Equilibrium in Social Systems', *Methodological Innovations* (2022) 15: 163–77. We shall not here delve into the controversial application of the theory of self-organised criticality to the evolutionary process itself.

48 For example, Per Bak and Maya Paczuski, 'Complexity, Contingency, and Criticality', *PNAS* (1995) 92: 6689–96; Bak, *How Nature*, 1–3, 49–61; Henrik Flyvbjerg, 'Simplest Possible, Self-Organized Critical System', *Physical Review Letters* (1996) 76: 940–3; Gregory Brunk, 'Why Do Societies Collapse? A Theory Based on Self-Organized Criticality', *Journal of Theoretical Politics* (2002) 14: 205–6; Deepah Dhar, 'Theoretical Studies of Self-Organized Criticality', *Physica A* (2006) 369: 29–70; Bosiljka Tadic, Alexander Shapoval and Mikhail Shnirman, 'Signatures of Self-Organized Dynamics in Rapidly Driven Critical Sandpiles', *Physical Review* (2024) 110: 1–11.

49 Henrik Jeldtoft Jensen, *Self-Organized Criticality: Emergent Complex Behavior in Physical and Biological Systems* (Cambridge: Cambridge University Press, 1998), 4, 16–17, 126–7; Carlo Ricotta, Giancarlo Avena and Marco Marchetti, 'The Flaming Sandpile: Self-Organized Criticality and Wildfires', *Ecological Modelling* (1999) 119: 73–7.

50 Hegel, *The Science*, 322.

51 Levins and Lewontin, *The Dialectical Biologist*, 280.

52 Cf. Scheffer, *Critical Transition*, 13.

53 See Tyler Volk, *CO_2 Rising: The World's Greatest Environmental Challenge* (Cambridge, MA: MIT Press, 2008).

54 This application of the theory of self-organised criticality slightly departs from the original version in one respect. The Danish physicists were intrigued by the 'power-law distribution' of slides and avalanches: there are many small ones and a few large ones in the sandpile or any other model they constructed (for the second generation of models, see below). The release of tension happens over and over again, at different scales. This is the nature of things – it's *How Nature Works*, per Bak's magnum opus. Virtually every system will organise itself into a state of criticality by repeating a general pattern of accumulating energy within itself. Here we apply the theory to *one particular historical process*, rather than seeing it as a universal truth under which systems generate the same power-law distribution of events – a notion that threatens to betray this theory's promise to pay attention to history.

55 Available as Monty Python, 'Mr Creosote', YouTube, 2014.

56 This reading of Mr Creosote (as well as other elements of the discussion of non-linear change) draws on Andreas Malm, *Det är vår bestämda uppfattning att om ingenting görs nu kommer det att vara för sent* (Stockholm: Atlas, 2007), 155. Mr Creosote was later, just in time for COP15 in Paris, picked up as an image of tipping points in the climate system by Johan Rockström, 'The Planet's Future Is in the Balance. But a Transformation Is Already Under Way', *Guardian*, 14 November 2015. The explosion of Mr Creosote was likened to the 'climate Minsky moment' in Phil McDuff, 'Climate Change Denial Won't Even Benefit Oil Companies Soon', *Guardian*, 31 July 2018. On the climate Minsky moment, see Malm and Carton, *Overshoot*, 150, 242.

57 Hegel, *The Science*, 321.

58 Engels, *Dialectics of Nature*, 66.

59 Thomas Kuhn's theory of scientific paradigms was another source of inspiration for the theory of punctuated equilibrium, which, in a loop, corroborated it: Gould, *The*

Structure, 967–70.

60 For a popular science survey, see Mark Buchanan, *Ubiquity: Why Catastrophes Happen* (New York: Crown, 2002); for a survey in the fields of physics and geosciences, Michael Gil, 'A Century of Nonlinearity in the Geosciences', *Earth and Space Science* (2019 6: 1007–42); for a survey of how ecosystems undergo abrupt shifts, Marten Scheffer, Steve Carpenter, Jonathan A. Foley et al., 'Catastrophic Shifts in Ecosystems', *Nature* (2001) 413: 591–6. For an astro-oriented survey from the pen of another Marxist legend, see Mike Davis, 'Cosmic Dangers on History's Stage? The Permanent Revolution in the Earth Sciences', *New Left Review* (1996) 217: 48–84. An excellent study in the field of ecology is Richard V. Solé and Jordi Bascompte, *Self-Organization in Complex Ecosystems* (Princeton: Princeton University Press, 2006). No better monograph on the topic exists, however, than Scheffer, *Critical Transitions*.

61 Scheffer, *Critical Transitions*, 20. Hysteresis comes from the Greek *husterein*, 'be behind', and is etymologically unrelated to the concept of hysteria, infamously derived from *hustera*, 'uterus'.

62 Svante Arrhenius, 'On the Influence of Carbonic Acid in the Air upon the Temperature of the Ground', *The London, Edinburgh, and Dublin Philosophical Magazine and Journal of Science* (1896) 41: 237–76. Arrhenius here 'took the most astonishing leap I have ever read in climate science'. Archer, *The Long*, 19.

63 *The Selma Morning Times*, 'Hint to Coal Consumers', 15 October 1902.

64 In fact, in a subsequent book, *Världarnas utveckling*, he wrote, well ahead of his time: 'The rate of carbonic acid [i.e. CO_2] in the atmosphere is so trifling that it can be noticeably perturbed by the influence of industry over the course of a few centuries.' Svante Arrhenius, *Världarnas utveckling* (Stockholm: Hugo Gebers, 1917), 54.

65 Stephen Weart, *The Discovery of Global Warming: Revised and Expanded Edition* (Cambridge, MA: Harvard University Press, 2008), 69.

66 Lecture by B. J. Mason referred to in John Gribbin, 'Man's Influence Not Yet Felt by Climate', *Nature* (1976) 264: 606. Mason did, however, open for the possibility that CO_2 emissions could 'produce a warming of 1–2°C' within fifty to 100 years.

67 As chronicled in Weart, *The Discovery*.

68 For example, Anthony D. Barnosky, Elizabeth A. Hadly, Jordi Bascompte et al., 'Approaching a State Shift in the Earth's Biosphere', *Nature* (2012): 53.

69 For example, Yasuto Watanabe, Ayako Abe-Ouchi, Fuyuki Saito et al., 'Astronomical Forcing Shaped the Timing of Early Pleistocene Glacial Cycles', *Communications Earth and Environment* (2023) 4: 1–11.

70 Richard B. Alley, *The Two-Mile Time Machine: Ice Cores, Abrupt Climate Change, and Our Future* (Princeton: Princeton University Press, 2000), 75–133; J. R. Petit, J. Jouzel, D. Raynaud et al., 'Climate and Atmospheric History of the Past 420,000 Years from the Vostok Ice Core, Antarctica', *Nature* (1999) 399: 429–36; Nicholas J. Shackleton, 'The 100,000-Year Ice-Age Cycle Identified and Found to Lag Temperature, Carbon Dioxide, and Orbital Eccentricity', *Science* (2000) 289: 1897–1901; Lee R. Kump, 'Reducing Uncertainty about Carbon Dioxide as a Climate Driver', *Nature* (2002) 419: 188–90. Another central such mechanism was, of course, the albedo effect (on which more below).

71 Alley, *The Two-Mile*, 120–8; Archer, *The Long*, 66; C. Lang, M. Leuenberger, J. Schwander et al., '16°C Rapid Temperature Variation in Central Greenland 70,000 Years Ago', *Science* (1999) 286: 934–8; Christof Huber, Markus Leuenberger, Renato Spahni et al., 'Isotope Calibrated Greenland Temperature Record over Marine Isotope Stage 3 and its Relation to CH_4', *Earth and Planetary Science Letters* (2006) 243: 504–19; E. W. Wolf, J. Chappellaz, T. Blunier et al., 'Millennial-Scale Variability during the Last

Glacial: The Ice Core Record', *Quaternary Science Reviews* (2010) 29: 2828–38; Victor Brovkin, Edward Brook, John W. Williams et al., 'Past Abrupt Changes, Tipping Points and Cascading Impacts in the Earth System', *Nature Geoscience* (2021) 14: 551–3. The mechanism behind these events remains disputed, but a popular theory points the finger to changing ocean currents and 'the rapid retreat of sea ice after the collapse of an ice shelf' – essentially, the global refrigerator rapidly diminishing in size. S. V. Petersen, D. P. Schrag and P. U. Clark, 'A New Mechanism for Dansgaard-Oeschger Cycles', *Paleoceanography and Paleoclimatology* (2013) 28: 24–30; Niklas Boers, Michael Ghil and Denis-Didier Rousseau, 'Ocean Circulation, Ice Shelf, and Sea Ice Interactions Explain Dansgaard–Oeschger Cycles', *PNAS* (2018) 115: 11005–14.

72 Cf. Scheffer, *Critical Transitions*, 139–40.

73 As argued in explicitly Gouldian fashion in John L. Brooke, *Climate Change and the Course of Global History: A Rough Journey* (Cambridge: Cambridge University Press, 2014); Denis-Didier Rousseau, Witold Bagniewski and Valerio Lucarini, 'A Punctuated Equilibrium Analysis of the Climate Evolution of Cenozoic Exhibits a Hierarchy of Abrupt Transitions', *Scientific Reports* (2023) 13: 1–13.

74 Alley, *The Two-Mile*, 83; cf. for example, 182. 'Climate records on timescales of millennia and shorter look like sudden flips from one climate state to another, rather than gradual transitions across a continuous range of climate states.' Archer, *The Long*, 67. 'The Earth's climate system has proven itself to be an angry beast. When nudged, it is capable of a violent response.' Wallace S. Broecker, 'Does the Trigger for Abrupt Climate Change Reside in the Ocean or in the Atmosphere?', *Science* (2003) 300: 1522.

75 On these four regimes, see Thomas Westerhold, Norbert Marwan, Anna Joy Drury et al., 'An Astronomically Dated Record of Earth's Climate and its Predictability over the Last 66 Million Years', *Science* (2020) 369: 1–5. The literature on abrupt paleoclimatic change is now bottomless. A great Gouldian summary can be found in Brooke, *Climate Change*, 1–108. Two fascinating syntheses are Daniel H. Rothman, 'Thresholds of Catastrophe in the Earth System', *Science Advances* (2017) 3: 1–12; Valerio Lucarini and Tamás Bódai, 'Edge States in the Climate System: Exploring Global Instabilities and Critical Transitions', *Nonlinearity* (2017) 30: 32–66.

76 See the rest of Brooke, *Climate Change*.

77 Richard B. Alley and Anna Maria Ágústsdóttir, 'The 8k Event: Cause and Consequence of a Major Holocene Abrupt Climate Change', *Quarternary Science Reviews* (2005) 24: 1123–49; A. N. LeGrande, G. A. Schmidt, D. T. Shindell and G. Hoffmann, 'Consistent Simulations of Multiple Proxy Responses to an Abrupt Climate Change Event', *PNAS* (2006) 103: 837–42.

78 Copenhagen University, 'One of World's Largest Glacier Floods Triggered in Greenland', 11 December 2024. Home institute: Niels Bohr Institute.

79 Guoxiong Zheng, Simon Keith Allen, Anming Bao et al., 'Increasing Risk of Glacial Lake Outburst Floods from Future Third Pole Deglaciation', *Nature Climate Change* (2021) 11: 411–17; Rayees Ahmed, Gowhar Farooq Wani, Syed Towseef Ahmad et al., 'A Review of Glacial Lake Expansion and Associated Glacial Lake Outburst Floods in the Himalayan Region', *Earth Systems and Environment* (2021) 5: 695–708; Caroline Taylor, Tom R. Robinson, Stuart Dunning et al., 'Glacial Lake Outburst Floods Threaten Millions Globally', *Nature Communications* (2023) 14: 1–10; Taigang Zhang, Weicai Wang, Baosheng An and Lele Wei, 'Enhanced Glacial Lake Activity Threatens Numerous Communities and Infrastructure in the Third Pole', *Nature Communications* (2023) 14: 1–12; Guoqing Zhang, Jonathan L. Carrivick, Adam Emmer et al., 'Characteristics and Changes of Glacial Lakes and Outburst Floods', *Nature Reviews Earth and Environment* (2024) 4: 447–62; Joel Michael, 'Devastating Glacial Lake

Outburst Causes Flash Floods in Sikkim', *Down To Earth*, 6 October 2023; Navin Singh Khadka, 'Sikkim: Deadly Indian Glacial Lake Flash Foods Exposes Lack of Warning System', BBC, 10 October 2023. Inevitably, there were muscular adaptationist calls for 'early warning systems' to address the danger. The occurrence of glacial lake outburst floods was steady until the 1970s, then gradually rose until the 1990s, when there was an abrupt spike and acceleration: Zhang et al., 'Characteristics and Changes', 450. There is an eerie correspondence between these punctuations and those in the class struggle.

80 Zheng et al., 'Inreasing Risk', 414–15. RCP8.5, that is.

81 Taylor et al., 'Glacial Lake', 3.

82 Morton Grodzin, 'Metropolitan Segregation', *Scientific American* (1957) 197: 33–41; Eleanor P. Wolf, 'The Tipping-Point in Racially Changing Neighborhoods', *Journal of the American Institute of Planners* (1962) 29: 217–22. On this as the first scientific use of the term, see Mark Nuttall, 'Tipping Points and the Human World: Living with Change and Thinking about the Future', *AMBIO* (2012) 41: 97–8; Egbert H. van Nes, Babak M. S. Arani, Arie Staal et al., 'What Do You Mean, "Tipping Point"?', *Trends in Ecology and Evolution* (2016) 31: 902. Grodzin originally used the phrase 'tip point'.

83 Cf. van Nes et al., 'What Do', 902–4.

84 Timothy M. Lenton, Hermann Held, Elmar Kriegler et al., 'Tipping Elements in the World System', *PNAS* (2008) 105: 1786–93. Cf. for example, James Hansen, 'Twenty Years Later: Tipping Points Near on Global Warming', *Guardian*, 23 June 2008; Andrew C. Revkin, 'Among Climate Scientists, a Dispute over "Tipping Points"', *New York Times*, 28 March 2009; Nutall, 'Tipping Points', 98. A popular science account caught whiff of the developments in the year before the appearance of the article by Lenton et al.: Fred Pearce, *With Speed and Violence: Why Scientists Fear Tipping Points in Climate Change* (Boston: Beacon, 2007). On the prehistory of the concept and the breakthrough caused by Lenton et al., see also Valerie N. Livina, 'Connected Climate Tipping Elements', *Nature Climate Change* (2023) 13: 15–16.

85 Scheffer, *Critical Transitions*. The book was habitually cited as such in papers on tipping points in the climate system. A more technical, mathematical survey covering similar ground is Solé, *Phase Transitions*.

86 Lenton et al., 'Tipping Elements', 1786. This phrase was the subtitle of a book that popularised the concept in journalistic vignettes on everything from epidemics to New York crime rates and briefly generated a buzz around the turn of the millennium: Malcolm Gladwell, *Tipping Point: How Little Things Can Make a Big Difference* (London: Little, Brown, 2000). Cf. the very similar definitions in van Nes, 'What Do', 904; Brovkin et al., 'Past Abrupt', 551; Elmar Kriegler, Jim W. Hall, Hermann Held et al., 'Imprecise Probability Assessment of Tipping Points in the Climate System', *PNAS* (2009) 106: 5041; Timothy M. Lenton and Hywel T. P. Williams, 'On the Origin of Planetary-Scale Tipping Points', *Trends in Ecology and Evolution* (2013) 28: 381; Seaver Wang, Adrianna Foster, Elizabeth A. Lenz et al., 'Mechanisms and Impacts of Earth System Tipping Elements', *Review of Geophysics* (2023) 61: 2–3.

87 Lenton et al., 'Tipping Elements', 1786 (for further formal elaborations, see 1786–7); David Armstrong McKay, Arie Staal, Jesse F. Abrams et al., 'Exceeding 1.5°C Global Warming Could Trigger Multiple Climate Tipping Points', *Science* (2022) 377: 1.

88 For example, van Nes, 'What Do', 903; Monica G. Turner, W. John Calder, Graeme S. Cumming et al., 'Climate Change, Ecosystems and Abrupt Change: Science Priorities', *Philosophical Transactions of the Royal Society B* (2019) 375: 5; Nico Wunderling, Ricarda Winkelmann, Johan Rockström et al., 'Global Warming Overshoots Increase Risks of Climate Tipping Cascades in a Network Model', *Nature Climate Change* (2023) 13: 75; and cf. Scheffer, *Critical Transitions*, 21, 24–5, 84, 104.

89 ‘In feedback loops, the comfortable concept of cause and effect loses its meaning, and so attempts to assign them usually end in frustration.’ Kump, ‘Reducing Uncertainty’, 189; and see further below.

90 This important distinction is made in Lenton et al., ‘Tipping Elements’, 1786.

91 Cf. for example, Brovkin et al., ‘Past Abrupt’, 550–1.

92 For example, Thomas F. Stocker and Olivier Marchal, ‘Abrupt Climate Change in the Computer: Is It Real?’, *PNAS* (2000) 97: 1362.

93 Cf. Reisinger and Geden, ‘Temporary Overshoot’, 1634; Jörg Schwinger, Ali Assadi, Norman Julius Steinert and Hanna Lee, ‘Emit Now, Mitigate Later? Earth System Reversibility under Overshoots of Different Magnitudes and Duration’, *Earth System Dynamics* (2022) 13: 1642; Carl-Friedrich Schleussner, Guarav Ganti, Quentin Lejeune et al., ‘Overconfidence in Climate Overshoot’, *Nature* (2024) 634: 366–373; Tessa Möller, Annika Ernest Högner, Carl-Friedrich Schleussner et al., ‘Achieving Net Zero Greenhouse Gas Emissions Critical to Limit Climate Tipping Risks’, *Nature Communications* (2024) 15: 1–11.

94 Cf. Henry Shue, *The Pivotal Generation: Why We Have a Moral Responsibility to Slow Climate Change Right Now* (Princeton: Princeton University Press, 2021), 99; Catriona McKinnon, *Climate Change and Political Theory* (Cambridge: Polity Press, 2022), 146.

95 Yongyang Cai, Kenneth L. Judd, Timothy M. Lenton et al., ‘Environmental Tipping Points Significantly Affect the Cost-Benefit Assessment of Climate Policies’, *PNAS* (2015) 112: 4606–11; Derek Lemoine and Christian P. Traeger, ‘Economics of Tipping the Climate Dominoes’, *Nature Climate Change* (2016) 6: 514–20; Yongyang Cai, Timothy M. Lenton and Thomas S. Lontzek, ‘Risk of Multiple Interacting Tipping Points Should Encourage Rapid CO_2 Emission Reduction’, *Nature Climate Change* (2016) 6: 520–5; Simon Dietz, James Rising, Thomas Stoerk and Gernot Wagner, ‘Economic Impacts of Tipping Points in the Climate System’, *PNAS* (2021) 118: 1–9; Christian L. E. Franzke, Alessio Ciullo, Elisabeth A. Gilmore et al., ‘Perspectives on Tipping Points in Integrated Models of the Natural and Human Earth System: Cascading Effects and Telecoupling’, *Environmental Research Letters* (2022) 17: 4–6. Cf. for example, R. B. Alley, J. Marotzke, W. D. Nordhaus et al., ‘Abrupt Climate Change’, *Science* (2003) 299: 2007–8; Simon Caney, ‘Climate Change and Future: Discounting for Time, Wealth, and Risk’, *Journal of Social Philosophy* (2009) 40: 173; Timothy M. Lenton, Johan Rockström, Owen Gaffney et al., ‘Climate Tipping Points: Too Risky to Bet Against’, *Nature* (2019) 575: 592.

96 In other words, by refusing to account for qualitative breaks in the climate, the IAMs protected capital from a burst of destruction and thereby increased the likelihood of such breaks – a loop between ideas and material reality if ever there was one.

97 See for example, Katharine Hayhoe and Robert E. Kopp, ‘What Surprises Lurk within the Climate System?’, *Environmental Research Letters* (2016) 11: 1–2.

98 Shinichiro Asayama, Rob Bellamy, Oliver Geden et al., ‘Why Setting a Climate Deadline Is Dangerous’, *Nature Climate Change* (2019) 9: 571.

99 Valérie Masson-Delmotte, Panmao Zhai, Anna Pirani et al., *Climate Change 2021: The Physical Science Basis. Contribution of Working Group 1 to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change* (Cambridge: Cambridge University Press, 2001), 197, 202–3. On the Panel paying scant attention to tipping points, cf. Luke Kemp, Chi Xu, Joanna Depledge et al., ‘Climate Endgame: Exploring Catastrophic Climate Change Scenarios’, *PNAS* (2022) 119: 1–9.

100 Quoted in Weart, *The Discovery*, 175.

101 Stefan Rahmstorf, Grant Foster and Anny Cazenave, ‘Comparing Climate Projections to Observations Up to 2011’, *Environmental Research Letters* (2012) 1–5; and see further

Ian Allison, Nathaniel Bindoff, Robert Bindschadler et al., *The Copenhagen Diagnosis: Updating the World on the Latest Climate Science* (Amsterdam: Elsevier, 2011); Keynyn Brysse, Naomi Oreskes, Jessica O'Reilly and Michael Oppenheimer, 'Climate Change Prediction: Erring on the Side of Least Drama?', *Global Environmental Change* (2013) 23: 327–37.

102 Brysse et al., 'Climate Change', 334; on the prophetic Gould, 333.

103 J. E. Hansen, 'Scientific Reticence and Sea Level Rise', *Environmental Research Letters* (2007) 2: 2; Alley et al., 'Abrupt Climate', 2007; Archer, *The Long*, 68 (see further 95–8).

104 As pointed out in Hayhoe and Kopp, 'What Surprises', 1.

105 K. D. Burke, J. W. Williams, M. A. Chandler et al., 'Pliocene and Eocene Provide Best Analogs for Near-Future Climates', *PNAS* (2018) 115: 13288–93. Cf. Lenton et al., 'Climate Tipping', 595.

106 Burke et al., 'Pliocene and Eocene', 13288 ('50 My' in original).

107 Karl Marx, *Grundrisse* (London: Penguin 1993 [1857–8]), 111.

108 Lenton et al., 'Tipping Elements', 1792.

109 Cf. Klaus Keller, Gary Yohe and Michael Schlesinger, 'Managing the Risks of Climate Thresholds: Uncertainties and Information Needs', *Climatic Change* (2008) 91: 5–10; Turner et al., 'Climate Change', 2; Kriegler et al., 'Imprecise Probability', 5041.

110 Lewontin, 'The Meaning', 22. Cf. Zhukov, 'How the Theory', 167; Barnosky et al., 'Approaching', 52; Scheffer, *Critical Transitions*, 62, 260–1, 283–95; Alan Hastings and Derin B. Wysham, 'Regime Shifts in Ecological Systems Can Occur with No Warning', *Ecology Letters* (2010) 13: 464–72; Carl Boettiger and Alan Hastings, 'From Patterns to Predictions', *Nature* (2013) 493: 157–8.

111 Lenin's statement is quoted in Simon Sebag Montefiore, 'What If the Revolution Had Never Happened?', *New York Times*, 6 November 2017, but it is apocryphal. 'We of the older generation may not live to see the decisive battles of this coming revolution', he told Swiss workers on 22 January 1917 in reference to the European revolution. Lars T. Lih, *Lenin* (London: Reaktion, 2011), 222.

112 Barnosky et al., 'Approaching', 55.

113 Lenton et al., 'Climate Tipping', 592; cf. Kemp et al., 'Climate Endgame', 5.

114 See Kriegler et al., 'Imprecise Probability', for example, 5045.

115 Dieter Gerten in Jonathan Watts, 'Climate Scientists Shocked by Scale of Floods in Germany', *Guardian*, 16 July 2021.

116 Gavin Schmidt, 'Climate Models Can't Explain 2023's Huge Heat Anomaly – We Could Be in Uncharted Territory', *Nature* (2024) 627: 467.

117 Sybren Drijfhout, Sebastian Bathiany, Claudie Beaulieu et al., 'Catalogue of Abrupt Shifts in Intergovernmental Panel on Climate Change Climate Models', *PNAS* (2015) 112: 5777–86. The term used in this study was not 'tipping point' but 'abrupt shift'; but the meaning is virtually the same.

118 Ibid., 5784.

119 Armstrong McKay et al., 'Exceeding 1.5°C' (quotation from 8). The two: Greenland and the West Antarctic ice sheet (see further below). The eight: those two, plus permafrost, AMOC, boreal forests, extra-polar glacier loss, coral reefs, Labrador-Irminger Sea convection (see further below).

120 Lenton and Williams, 'On the Origin', 382.

121 On such conceptual drift, see Henrik Thorén and Johannes Persson, 'Philosophy of Interdisciplinarity: Problem-Feeding, Conceptual Drift, and Methodological Migration', paper presented at the Third Biennial Conference of the Society for Philosophy of Science in Practice, 22–24 June 2011, Exeter.

122 On such a ‘fork in the road’ after which certain technologies and relations are firmly established, cf. Will Steffen, Johan Rockström, Katherine Richardson et al., ‘Trajectories of the Earth System in the Anthropocene’, *PNAS* (2018) 115: 8253.

123 Cf. Lenton and Williams, ‘On the Origin’, 381.

124 Masson-Delmotte et al., *Climate Change*, 177.

125 John Abraham, ‘We Study Ocean Temperatures. The Earth Just Broke a Heat Increase Record’, *Guardian*, 11 January 2022 (seven atomic bombs of the size dropped on Hiroshima).

126 John Abraham, Lijing Cheng, Michael E. Mann et al., ‘The Ocean Response to Climate Change Guides both Adaptation and Mitigation Efforts’, *Atmospheric and Oceanic Science Letters* (2022) 15: 3.

127 Dana Ehlert and Kirsten Zickfeld, ‘Irreversible Ocean Thermal Expansion under Carbon Dioxide Removal’, *Earth System Dynamics* (2018) 9: 197–210. This study supersedes N. Bouttes, J. M. Gregory and J. A. Lowe, ‘The Reversibility of Sea Level Rise’, *Journal of Climate* (2013) 26: 2502–13. Ehlert and Zickfeld align with Katarzyna B. Tokarska and Kirsten Zickfeld, ‘The Effectiveness of Net Negative Carbon Dioxide Emissions in Reversing Anthropogenic Climate Change’, *Environmental Research Letters* (2015) 10: 1–11.

128 Ehlert and Zickfeld, ‘Irreversible Ocean’, 207. Cf., for example, Yang et al., ‘Reversibility of Historical’, 1064, 1067.

129 Cf. ibid., 207; Bouttes et al., ‘The Reversibility’, 2503.

130 Martin Truffer and Mark Fanhestock, ‘Rethinking Ice Sheet Time Scales’, *Science* (2007) 315: 1508.

131 Eric Rignot, ‘Changes in Ice Dynamics and Mass Balance of the Antarctic Ice Sheet’, *Philosophical Transactions of the Royal Society A* (2006) 364: 1637. For similar critique from the same historical moment, on which more below, see, for example, Richard A. Kerr, ‘A Worrying Trend of Less Ice, Higher Seas’, *Science* (2006) 311: 1698–1701; Ian Joughin, ‘Greenland Rumbles Louder as Glaciers Accelerate’, *Science* (2006) 311: 1719–20.

132 Down from eighty-eight centimetres in the third report from 2001: for an overview of the ranges given in the reports, see S. Sadai, R. A. Spector, R. DeConto and N. Gomez, ‘The Paris Agreement and Climate Justice: Inequitable Impacts of Sea Level Rise Associated with Temperature Targets’, *Earth’s Future* (2022) 10: 4.

133 Masson-Delmotte et al., *Climate Change*, 282.

134 Susan Solomon, Dahe Qin, Martin Manning et al., *Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change* (Cambridge: Cambridge University Press, 2007), 361.

135 Christopher Rapley in Alister Doyle, ‘Islands Emerge as Arctic Ice Shrinks to Record Low’, *Reuters*, 21 August 2007.

136 Hansen, ‘Scientific Reticence’.

137 Richard A. Kerr, ‘Pushing the Scary Side of Global Warming’, *Science* (2007) 316: 1412–15; Stefan Rahmstorf, Anny Cazenave, John A. Church et al., ‘Recent Climate Observations Compared to Projections’, *Science* (2007) 316: 709; Alexandra Witze, ‘Losing Greenland’, *Nature* (2008) 452: 801.

138 This was the upper bound in the Panel’s *Special Report on the Ocean and Cryosphere in a Changing Climate*; for a discussion, see Martin Siegert, Richard B. Alley, Eric Rignot et al., ‘Twenty-First Century Sea-Level Rise Could Exceed IPCC Projections for Strong-Warming Futures’, *One Earth* (2020) 3: 691–703.

139 Siegert et al., ‘Twenty-First’, 698. For a more recent testimony to the crisis, see Jonathan P. Rosser, Ricarda Winkelmann and Nico Wunderling, ‘Polar Ice Sheets Are Decisive Contributions to Uncertainty in Climate Tipping Projections’, *Communications Earth and Environment* (2024) 5: 1–11.

140 Masson-Delmotte et al., *Climate Change*, 77, 1308.

141 Andy Aschwanden, Timothy C. Bartholomaus, Douglas J. Brinkerhoff and Martin Truffer, ‘A Roadmap towards Credible Projections of Ice Sheet Contribution to Sea Level Rise’, *Cryosphere* (2021) 15: 5705.

142 Ibid., 5706.

143 What remains of them, that is: Siegert at al., ‘Twenty-First Century’, 692.

144 Armstrong McKay et al., ‘Exceeding 1.5°C’, 5. The estimated range here was for 1.5°C to 3°C, with 2°C as the ‘best estimate’; similarly, the timescale could be between fifty and 1,000 years. Cf. the similar ranges in David R. Rounce, Regine Hock, Fabien Maussion et al., ‘Global Glacier Change in the 21st Century: Every Increase in Temperature Matters’, *Science* (2023) 379: 78–83.

145 Rounce et al., ‘Global Glacier’, 6; International Cryosphere Climate Initiative [hereafter ICCI], *Cryosphere 1.5°: Where Urgency and Ambition Meet*, December 2019, 10–12.

146 Witze, ‘Losing Greenland’, 799. It was this source John Moore and colleagues wanted to wall up: Moore et al., ‘Targeted Geoengineering’, 111.

147 Ian Joughin, Waleed Abdalati and Mark Fahnestock, ‘Large Fluctuations in Speed on Greenland’s Jakobshavn Isbrae Glacier’, *Nature* (2004) 432: 608–10; Julian A. Dowdeswell, ‘The Greenland Ice Sheet and Global Sea Level Rise’, *Science* (2006) 311: 963–4; Robert Bindschadler, ‘Hitting the Ice Sheets Where It Hurts’, *Science* (2006) 311: 1720–1; David G. Vaughan and Robert Arthern, ‘Why Is It Hard to Predict the Future of Ice Sheets?’, *Science* (2007) 315: 1503–4; Ian M. Howat, Ian Joughin and Ted A. Scambos, ‘Rapid Changes in Ice Discharge’, *Science* (2007) 315: 1559–61; Ryan K. Cassotto, Justin C. Burton, Jason M. Admundson et al., ‘Granular Decoherence Precedes Ice Mélange Failure and Glacier Calving at Jakobshavn Isbrae’, *Nature Geoscience* (2021) 14: 417–22; R. Millan, E. Jager, M. H. Wood et al., ‘Rapid Disintegration and Weakening of Ice Shelves in North Greenland’, *Nature Communications* (2023) 14: 1–9; Anja Løkkegaard, William Colgan, Karin Hansen et al., ‘Ice Acceleration and Rotation in the Greenland Ice Sheet Interior in Recent Decades’, *Communications Earth and Environment* (2024) 5: 1–12 – a study demonstrating that the fractures are propagated deep inland, the glacier of the Jakobshavn Isbrae now flowing towards the shore one hundred kilometres away from the terminus; Siegert et al., ‘Twenty-First Century’, 693.

148 Kristian Svennevig, Stephen P. Hicks, Thomas Forbriger et al., ‘A Rockslide-Generated Tsunami in a Greenland Fjord Rang Earth for 9 Days’, *Science* (2024) 385: 1196–1205.

149 Damian Carrington, ‘Entire Earth Vibrated for Nine Days after Climate-Triggered Mega-tsunami’, *Guardian*, 12 September 2024.

150 Thomas R. Chudley, Ian M. Howat, Michaela D. King and Emma J. MacKie, ‘Increased Crevassing across Accelerating Greenland Ice Sheet Margins’, *Nature Geoscience* (2025) 18: 148–53.

151 Witze, ‘Loosing Greenland’, 798, 800–1; Quirin Schiermeier, ‘A Rising Tide’, *Nature* (2004) 428: 114–15; Eric Rignot and Pannir Kanagaratnam, ‘Changes in the Velocity Structure of the Greenland Ice Sheet’, *Science* (2006) 311: 986–90; S. B. Lutchke, H. J. Zwally, W. Abdalati et al., ‘Recent Greenland Ice Mass Loss by Drainage System from Satellite Gravity Observations’, *Science* (2006) 314: 1286–9; Robin Bell, ‘The Role of Subglacial Water in Ice-Sheet Mass Balance’, *Nature Geoscience* (2008) 1: 297–304;

Tun Jan Young, Poul Christoffersen, Marion Bougamont et al., 'Rapid Basal Melting of the Greenland Ice Sheet from Surface Meltwater Drainage', *PNAS* (2022) 119: 1–8.

152 Quoted in Pearce, *With Speed*, 42 (see further 41–5).

153 Michaela D. King, Ian M. Howat, Salvatore G. Candela et al., 'Dynamic Ice Loss from the Greenland Ice Sheet Driven by Sustained Glacier Retreat', *Communications Earth and Environment* (2020) 1: 1–7; and for more on the dominance of dynamics, see, for example, Jason E. Box, Alun Hubbard, David B. Bahr et al., 'Greenland Ice Sheet Climate Disequilibrium and Committed Sea-Level Rise', *Nature Climate Change* (2022) 12: 808–13.

154 Youngmin Choi, Mathieu Morlighem, Eric Rignot and Michael Wood, 'Ice Dynamics Will Remain a Primary Driver of Greenland Ice Sheet Mass Loss over the Next Century', *Communications Earth and Environment* (2021) 2: 1–8.

155 T. R. Chudley, I. M. Howat, M. D. King and A. Negrete, 'Atlantic Water Intrusion Triggers Rapid Retreat and Regime Change at Previously Stable Greenland Glacier', *Nature Communications* (2023) 14: 1–10. Name of the glacier: Steenstrup.

156 See further Jonathan C. Ryan, 'Contribution of Surface and Cloud Radiative Feedbacks to Greenland Ice Sheet Meltwater Production during 2002–2023', *Communications Earth and Environment* (2024) 5: 1–9.

157 Niklas Boers and Martin Rypdal, 'Critical Slowing Down Suggests that the Western Greenland Ice Sheet Is Close to a Tipping Point', *PNAS* (2021) 118: 1–7; Dennis Höning, Matteo Willeit, Reinhard Calov et al., 'Multistability and Transient Response of the Greenland Ice Sheet to Anthropogenic CO_2 Emissions', *Geophysical Research Letters* (2023) 50: 1–11; cf. Lenton et al., 'Climate Tipping', 592; Armstrong McKay et al., 'Exceeding 1.5°C', 3. See also Alexander Robinson, Reinhard Calov and Andrey Ganopolski, 'Multistability and Critical Thresholds of the Greenland Ice Sheet', *Nature Climate Change* (2012) 2: 429–32. One study found that there was already a committed – unavoidable, that is – sea level rise of at least twenty-seven centimetres from Greenland, as of the beginning of the 2020s: Box et al., 'Greenland Ice'.

158 Nil Irvali, Eirik V. Galaasen, Ulysses S. Ninnemann et al., 'A Low Climate Threshold for South Greenland Ice Sheet Demise during the Late Pleistocene', *PNAS* (2020) 117: 190–5.

159 Nils Bochow, Anna Poltronieri, Alexander Robinson et al., 'Overshooting the Critical Threshold for the Greenland Ice Sheet', *Nature* (2023) 622: 528–36.

160 Boers and Rypdal, 'Critical Slowing'.

161 See, for example, ibid; Robinson et al., 'Multistability and Critical', 431; Irvali et al., 'A Low Climate', 192–3.

162 Bochow et al., 'Overshooting the Critical'; cf. Höning et al., 'Multistability and Transient', 6.

163 Höning et al., 'Multistability and Transient', 3; ICCI, *Cryosphere 1.5°*, 6. Cf. Bochow et al., 'Overshooting the Critical', 530; Robinson et al., 'Multistability and Critical', 432.

164 Dennis Höning, Matteo Willeit and Andrey Ganopolski, 'Reversibility of Greenland Ice Sheet Mass Loss under Artificial Carbon Dioxide Removal Scenarios', *Environmental Research Letters* (2024) 19: 1–9.

165 Earth Observatory, 'World of Change: Collapse of the Larsen-B Ice Shelf', n.d.; Nicola Jones, 'Giant Antarctic Ice Sheet Breaks Off', *New Scientist*, 19 March 2002; Andrew Shepherd, Duncan Wingham, Tony Payne and Pedro Skvarca, 'Larsen Ice Shelf Has Progressively Thinned', *Science* (2003) 302: 856–9; T. A. Scambos, J. A. Bohlander, C. A. Shuman and P. Skvarca, 'Glacier Acceleration and Thinning after Ice Shelf Collapse in the Larsen B Embayment, Antarctica', *Geophysical Research Letters* (2004) 31: 1–4; Andrew Shepherd, Duncan Wingham and Eric Rignot, 'Warm Ocean Is Eroding West

Antarctic Ice Sheet', *Geophysical Research Letters* (2004) 31: 1–4; H. D. Pritchard and D. G. Vaughan, 'Widespread Acceleration of Tidewater Glaciers on the Antarctic Peninsula', *Journal of Geophysical Research* (2007) 112: 1–10; Robert M. DeConto, David Pollard, Richard B. Alley et al., 'The Paris Climate Agreement and Future Sea-Level Rise from Antarctica', *Nature* (2021) 593: 84. On the collapse of Larsen B as a shock to the gradualist paradigm, cf. Michael Edgeworth McIntyre, 'Climate Tipping Points: A Personal View', *Physics Today* (2023) 76: 47.

166 R. Thomas, E. Rignot, G. Casassa et al., 'Accelerated Sea-Level Rise from West Antarctica', *Science* (2004) 306: 255–8; Eric Rignot, 'Changes in Ice Dynamics and Mass Balance of the Antarctic Ice Sheet', *Philosophical Transactions of the Royal Society of London A* (2006) 364: 1642, 1649; Robert M. DeConto and David Pollard, 'Contribution of Antarctica to Past and Future Sea-Level Rise', *Nature* (2016) 531: 591–3; Nicholas R. Golledge and Daniel P. Lowry, 'Is the Marine Ice Cliff Hypothesis Collapsing?', *Science* (2021) 372: 1266–7; J. N. Bassis, B. Berg, A. J. Crawford and D. I. Benn, 'Transition to Marine Ice Cliff Instability Controlled by Ice Thickness Gradients and Velocity', *Science* (2021) 372: 1–3; Justine Caillet, Nicolas C. Jourdain, Pierre Mathiot et al., 'Drivers and Reversibility of Abrupt Ocean State Transitions in the Amundsen Sea, Antarctica', *Journal of Geophysical Research: Oceans* (2023) 128: 1–19; Siegert et al., 'Twenty-First Century', 693–6; DeConto et al., 'The Paris Climate', 84, 88.

167 P. Milillo, E. Rignot, P. Rizzoli et al., 'Rapid Glacier Retreat Rates Observed in West Antarctica', *Nature Geoscience* (2022) 15: 48–53; Christine L. Batchelor, Frazer D. W. Christie, Dag Ottesen et al., 'Rapid, Buoyancy-Driven Ice-Sheet Retreat of Hundreds of Meters Per Day', *Nature* (2023) 617: 105–10.

168 Alexander T. Bradley and Ian J. Hewitt, 'Tipping Point in Ice-Sheet Grounding-Zone Melting due to Ocean Water Intrusion', *Nature Geoscience* (2024) 17: 631–7. Note how a study like this one applied the concept of tipping points to very localised ice dynamics too, suggestive of the fractal character of nodal points and slides.

169 Ariaan Purich and Edward W. Doddridge, 'Record Low Antarctic Sea Ice Coverage Indicates a New Sea Ice State', *Communications Earth and Environment* (2023) 4: 1–9.

170 Matt King, director of the Australian Centre for Excellence in Antarctic Science, in Adam Morton and Graham Readfearn, 'Red Alert in Antarctica: The Year Rapid, Dramatic Change Hit Climate Scientists Like a "Punch in the Guts"', *Guardian*, 30 December 2023. '"Unprecedented is a word that gets bandied around a lot, but it doesn't really get to just how shocking this is," says [Will] Hobbs, a sea ice scientist at the University of Tasmania. "It is very much outside our understanding of this system."' Graham Readfearn, '"Something Weird Is Going On": Search for Answers as Antarctic Sea Ice Stays at Historic Lows', *Guardian*, 29 July 2023. 'I think everyone's asking what's happening right now. It's unbelievable': Ariaan Purich (of Purich and Doddridge, 'Record Low') in ibid.

171 Duncan J. Wingham, Martin J. Siegert, Andrew Shepherd and Alan S. Muir, 'Rapid Discharge Connects Antarctic Subglacial Lakes', *Nature* (2006) 440: 1033–6; A. M. Smith, T. Murray, K. W. Nicholls et al., 'Rapid Erosion, Drumlin Formation, and Changing Hydrology beneath an Antarctic Ice Stream', *Geology* (2007) 35: 127–30; Helen Amanda Fricker, Ted Scambos, Robert Bindschadler and Laurie Padman, 'An Active Subglacial Water System in West Antarctica Mapped from Space', *Science* (2007) 315: 1544–7; Julius Garbe, Torsten Albrecht, Anders Levermann et al., 'The Hysteresis of the Antarctic Ice Sheet', *Nature* (2020) 585: 538, 542.

172 Garbe et al., 'The Hysteresis', 539.

173 Ibid., 540–2; Wang et al., ‘Mechanisms and Impacts’, 18–19; Armstrong McKay et al., ‘Exceeding 1.5°C’, 3–4, 7; ICCI, *Cryosphere 1.5°*, 1, 5, 7; Johannes Feldmann and Anders Levermann, ‘Collapse of the West Antarctic Ice Sheet after Local Destabilization of the Amundsen Basin’, *PNAS* (2015) 112: 14191–6; Kaitlin A. Naughten, Paul R. Holland and Jan De Rydt, ‘Unavoidable Future Increase in West Antarctic Ice-Shelf Melting over the Twenty-First Century’, *Nature Climate Change* (2023) 13: 1222–8; see also, for example, N. R. Golledge, P. U. Clark, A. Dutton et al., ‘Retreat of the Antarctic Ice Sheet during the Last Interglaciation and Implications for Future Change’, *Geophysical Research Letters* (2021) 48: 1–11. In the original Lenton et al., ‘Tipping Elements’, the range for a tipping point in Western Antarctica was put at 3–5°C: 1788. The revisions have indeed been fast. The 2°C point was stated as late as in Kemp et al., ‘Climate Endgame’, 6.

174 Ian Joughin, Benjamin E. Smith and Brooke Medley, ‘Marine Ice Sheet Collapse Potentially Under Way for the Thwaites Glacier Basin, West Antarctica’, *Science* (2014) 344: 735–8; Hongju Yu, Eric Rignot, Helene Seroussi et al., ‘Impact of Iceberg Calving on the Retreat of Thwaites Glacier, West Antarctica over the Next Century with Different Calving Laws and Ocean Thermal Forcing’, *Geophysical Research Letters* (2019) 46: 14539–47.

175 Lenton et al., ‘Climate Tipping’, 592; Naughten et al., ‘Unavoidable Future’, 1227 (‘the sheet’ in original: ‘WAIS’).

176 Naughten et al., ‘Unavoidable Future’, 1227.

177 M. Mengel and A. Levermann, ‘Ice Plug Prevents Irreversible Discharge from East Antarctica’, *Nature Climate Change* (2014) 4: 451–5; Esmee M. van Wijk, Stephen R. Rintoul, Luke O. Wallace et al., ‘Vulnerability of Denman Glacier to Ocean Heat Flux Revealed by Profiling Float Observations’, *Geophysical Research Letters* (2022) 49: 1–9; Chris R. Stokes, Nerilie J. Abram, Michal J. Bentley et al., ‘Response of the East Antarctic Ice Sheet to Past and Future Climate Change’, *Nature* (2022) 608: 275–86; Wang et al., ‘Mechanisms and Impacts’, 14–15.

178 Emily A. Hill, G. Hilmar Gudmundsson and David M. Chandler, ‘Ocean Warming as a Trigger for Irreversible Retreat of the Antarctic Ice Sheet’, *Nature Climate Change* (2024) 14: 1165–71.

179 Edward Blanchard-Wrigglesworth, Tyler Cox, Zachary I. Espinosa and Aaron Donohoe, ‘The Largest Ever Recorded Heatwave: Characteristics and Attribution of the Antarctic Heatwave of March 2022’, *Geophysical Research Letters* (2023) 50: 1–11.

180 Garbe et al., ‘The Hysteresis’, 538–41; Armstrong McKay et al. ‘Exceeding 1.5°C’, 4–5; Wang et al., ‘Mechanisms and Impacts’, 15–19.

181 DeConto et al., ‘The Paris Climate’, 88. ‘Our results imply that, if the Paris Agreement to limit global warming well below 2°C above pre-industrial temperatures is not met, one or more critical thresholds might be subsequently crossed in Antarctica, committing us to long-term, possibly irreversible, sea-level rise of up to dozens of metres.’ Garbe et al., ‘The Hysteresis’, 543.

182 Garbe et al., ‘The Hysteresis’, 541.

183 Matthias Mengel, Alexander Nauels, Joeri Rogelj and Carl-Friedrich Schleussner, ‘Committed Sea-Level Rise under the Paris Agreement and the Legacy of Delayed Mitigation Action’, *Nature Communications* (2018) 9: 4. Cf. Jaime B. Palter, Thomas L. Frölicher, David Paynter and Jasmin G. John, ‘Climate, Ocean Circulation, and Sea Level Changes under Stabilization and Overshoot Pathways to 1.5K Warming’, *Earth System Dynamics* (2018) 9: 817–28.

184 ICCI, *Cryosphere 1.5°*, 1, 5.

185 Cf. Zickfeld et al., ‘Long-Term Climate’, 5782, 5789, 5798, 5807.

186 Levins and Lewontin, *The Dialectical Biologist*, 280.
187 Stefan Rahmstorf, 'Ocean Circulation and Climate during the Past 120,000 Years', *Nature* (2002) 419: 207–14; Paul A. T. Higgins, Michael D. Mastrandrea and Stephen H. Schneider (2002), 'Dynamics of Climate and Ecosystem Coupling: Abrupt Changes and Multiple Equilibria', *Philosophical Transactions of the Royal Society of London B* (2002) 357: 647–55; Alley, *The Two-Mile*, 135, 140–58; Masson-Delmotte et al., *Climate Change*, 483.
188 Levins and Lewontin, *The Dialectical Biologist*, 282.
189 Alley, *The Two-Mile*, 149–54.
190 W. S. Broecker, 'Does the Trigger for Abrupt Climate Change Reside in the Ocean or in the Atmosphere?', *Science* (2003) 300: 1519–22; Wallace S. Broecker, 'Abrupt Climate Change Revisited', *Global and Planetary Change* (2006) 54: 211–25; Richard B. Alley, 'Wally Was Right: Predictive Ability of the North Atlantic "Conveyor Belt" Hypothesis for Abrupt Climate Change', *Annual Review of Earth and Planetary Science* (2007) 35: 241–72; Bryan Shuman, 'Patterns, Processes, and Impacts of Abrupt Climate Change in a Warm World: The Past 11,700 Years', *WIREs Climate Change* (2012) 3: 26–7; Jean Lynch-Stieglitz, 'The Atlantic Meridional Overturning Circulation and Abrupt Climate Change', *Annual Review of Marine Science* (2017) 9: 83–104; Alley and Ágústsdóttir, 'The 8k Event', 1133–4; A. N. LeGrande et al., 'Consistent Simulations'; Rahmstorf, 'Ocean Circulation'.
191 The exact effect in part appears to depend on where exactly freshwater enters the circulation: Qiyun Ma, Xiaoxu Shi, Patrick Scholz et al., 'Revisiting Climate Impacts of An AMOC Slowdown: Dependence on Freshwater Locations in the North Atlantic', *Science Advances* (2024) 10: 1–15.
192 Drijfhout et al., 'Catalogue of Abrupt', 5782.
193 Paul D. L. Ritchie, Greg S. Smith, Katrina J. Davis et al., 'Shifts in National Land Use and Food Production in Great Britain after a Climate Tipping Point', *Nature Food* (2020) 1: 76–83. Similar findings are reported in Richard A. Wood, Michael Vellinga and Robert Thorpe, 'Global Warming and Thermohaline Circulation Stability', *Philosophical Transactions of the Royal Society of London A* (2002) 361: 1961–75.
194 René M. van Westen, Michael Kliphuis and Henk A. Dijkstra, 'Physics-Based Early Warning Signal Shows that AMOC Is on Tipping Course', *Science Advances* (2024) 10: 4.
195 Ritchie et al., 'Shifts in National', 76.
196 Stefan Rahmstorf, 'Is the AMOC Shutting Down?', YouTube, Arctic Circle Assembly, 19 October 2024.
197 van Westen et al., 'Physics-Based Early', 7 (emphasis added). Total cooling could range between 5 and 15°C: ibid., 3.
198 Ibid., 7.
199 Bochow et al., 'Overshooting the Critical', 535; the collapse is welcomed in Schwinger et al., 'Emit Now', 1656. The cooling of Greenland is only a brief reprieve in Ann Kristin Klose, Jonathan F. Donges, Ulrike Feudel and Ricarda Winkelmann, 'Rate-Induced Tipping Cascades Arising from Interactions between the Greenland Ice Sheet and the Atlantic Meridional Overturning Circulation', *Earth System Dynamics* (2024) 15: 635–52.
200 Paul A. T. Higgins and Michael Vellinga, 'Ecosystem Responses to Abrupt Climate Change: Teleconnections, Scale and the Hydrological Cycle', *Climatic Change* (2004) 64: 139–40; Michael Vellinga and Richard A. Wood, 'Impacts of Thermohaline Circulation Shutdown in the Twenty-First Century', *Climatic Change* (2008) 91: 43–63; Wood et al., 'Global Warming'; Alley and Ágústsdóttir, 'The 8k Event', 1140. There

could also be a global hiatus in the warming, lasting for a couple of decades in the 'best' case, much like after a major volcanic eruption or reduction in solar radiation. Sybren Drijfhout, 'Competition between Global Warming and an Abrupt Collapse of the AMOC in Earth's Energy Imbalance', *Scientific Reports* (2015) 5: 1–11.

201 Alley, *The Two-Mile*, 143; cf. for example, Wallace S. Broecker, 'The Great Ocean Conveyor', *Oceanography* (1991) 79–89.

202 Alley, *The Two-Mile*, 184; Vellinga and Wood, 'Impacts of Thermohaline'; Wang et al., 'Mechanisms and Impacts', 8.

203 Hartmut Shulz, Ulrich von Rad and Helmut Erlenkeuser, 'Correlation between Arabian Sea and Greenland Climate Oscillations of the Past 100,000 Years', *Nature* (1998) 393: 54–7; John C. H Chiang and Athanasios Koutavas, 'Tropical Flip-Flop Connections', *Nature* (2004) 432: 684–5; Michael E. Schlesinger, Jianjun Yin, Gary Yohe et al., 'Assessing the Risk of a Collapse of the Atlantic Thermohaline Circulation', in Hans Joachim Schellnhuber, Paul J. Crutzen, William C. Clark et al. (eds), *Avoiding Dangerous Climate Change* (Cambridge: Cambridge University Press, 2006), 37–48; Higgins and Vellinga, 'Ecosystem Responses'; Masson-Delmotte et al., *Climate Change*, 1148. Conversely, a slowdown in the North Atlantic could cause more tropical cyclones in the Gulf of Mexico: Emma Levin, Joshua Studholme, Alexey Fedorov et al., 'Atlantic Ocean Circulation Slowdown Intensifies Tropical Cyclones in the North Atlantic', *Research Square* (2024), preprint, *Nature* portfolio.

204 Matthew S. Lachniet, Yemane Asmerom, Juan Pablo Bernal and Lorenzo Vazquez-Selem, 'Orbital Pacing and Ocean Circulation-Induced Collapses of the Mesoamerican Monsoon over the Past 22,000 y', *PNAS* (2013) 110: 9255–60.

205 See, for example, Anil K. Gupta, David M. Anderson and Jonathan T. Overpeck (2003), 'Abrupt Changes in the Asian Southwest Monsoon during the Holocene and Their Links to the North Atlantic Ocean', *Nature* (2003) 421: 354–6; B. N. Goswami, M. S. Madhusoodanan, C. P. Neema and D. Sengupta, 'A Physical Mechanism for North Atlantic SST Influence on the Indian Summer Monsoon', *Geophysical Research Letters* (2006) 33: 1–4.

206 EPICA Community Members, 'One-to-One Coupling of Glacial Climate Variability in Greenland and Antarctica', *Nature* (2006) 444: 195–8; J. Jouzel, V. Masson-Delmotte, O. Cattani et al., 'Orbital and Millennial Antarctic Climate Variability over the Past 800,000 Years', *Science* (2007) 317: 793–6.

207 Anders Levermann, Alexa Griesel, Matthias Hofmann et al., 'Dynamic Sea Level Changes Following Changes in the Thermohaline Circulation', *Climate Dynamics* (2005) 24: 347–54.

208 Peter Ditlevsen and Susanne Ditlevsen, 'Warning of a Forthcoming Collapse of the Atlantic Meridional Overturning Circulation', *Nature Communications* (2023) 14: 1. On the documentation since 2004, cf. Wang et al., 'Mechanisms and Impacts', 6. For signs of earlier weakening, see L. Caesar, S. Rahmstorf, A. Robinson et al., 'Observed Fingerprint of a Weakening Atlantic Ocean Overturning Circulation', *Nature* (2018) 556: 191–6. The IPCC recognises the weakening in Masson-Delmotte et al., *Climate Change*, 1320.

209 On river run-off, see, for example, Bruce J. Peterson, James McClelland, Ruth Curry et al., 'Trajectory Shifts in the Arctic and Subarctic Freshwater Cycle', *Science* (2006) 313: 1061–66; Asa K. Rennermalm, Eric F. Wood, Stephen J. Déry et al., 'Sensitivity of the Thermohaline Circulation to Arctic Ocean Runoff', *Geophyscal Research Letters* (2006) 33: 1–4.

210 L. Caesar, G. D. McCarthy, D. J. R. Thornalley et al., 'Current Atlantic Meridional Overturning Circulation Weakest in Last Millennium', *Nature Geoscience* (2021) 14:

118–20.

211 On the warming hole and its future, see Wei Liu, Alexey V. Fedorov, Shang-Ping Xie and Shineng Hu, ‘Climate Impacts of a Weakened Atlantic Meridional Overturning Circulation in a Warming Climate’, *Science Advances* (2020) 6: 1–8.

212 Aurélie Duchez, Eleanor Frajka-Williams, Simon A. Josey et al., ‘Drivers of Exceptionally Cold North Atlantic Ocean Temperatures and their Link to the 2015 European Heat Wave’, *Environmental Research Letters* (2016) 11: 1–9.

213 Paul B. Goddard, Jianjun Yin, Stephen M. Griffies and Shaoqing Zhang, ‘An Extreme Event of Sea-Level Rise along the Northeast Coast of North America in 2009–2010’, *Nature Communications* (2015) 6: 1–8.

214 Detlef Quadfasel, ‘The Atlantic Heat Conveyor Slows’, *Nature* (2005) 438: 566 (emphasis added). On punctuated equilibrium and Gould in AMOC, see Pearce, *With Speed*, 145. For the details of tipping dynamics, see further Johannes Lohmann and Peter D. Ditlevsen, ‘Risk of Tipping the Overturning Circulation Due to Increasing Risk of Ice Melt’, *PNAS* (2021) 118: 1–6.

215 Hans-Otto Pörtner, Debra C. Roberts, Valerie Masson-Delmotte et al. (eds), *IPCC Special Report on the Ocean and Cryosphere in a Changing Climate* (Cambridge: Cambridge University Press, 2019), 595, 617–20.

216 Armstrong Mckay et al., ‘Exceeding 1.5°C’, 5.

217 Ibid. On the gradualist errors, see further Wei Liu, Shang-Ping Xie, Zhengyu Liu and Jiang Zhu, ‘Overlooked Possibility of a Collapsed Atlantic Meridional Overturning Circulation in Warming Climate’, *Science Advances* (2017) 3: 1–7; Wang et al., ‘Mechanisms and Impacts’, 5.

218 Masson-Delmotte et al., *Climate Change*, 1148.

219 Ibid., 1239.

220 Armstrong Mckay et al., ‘Exceeding1.5°C’, 5; see also Drijfhout et al., ‘Catalogue of Abrupt’, E5782; Wang et al., ‘Mechanisms and Impacts’, 7.

221 Ditlevsen and Ditlevsen, ‘Warning of a Forthcoming’, 7.

222 Niklas Boers, ‘Observation-Based Early-Warning Signals for a Collapse of the Atlantic Meridional Overturning Circulation’, *Nature Climate Change* (2021) 11: 680–88; Chad A. Greene, Alex S. Gardner, Michael Wood and Joshua K. Cuzzone, ‘Ubiquitous Acceleration in Greenland Ice Sheet Calving from 1985 to 2022’, *Nature* (2024) 625: 527; Boers and Rypdal, ‘Critical Slowing’, 1; and see also Stefan Rahmstorf, ‘Is the Atlantic Overturning Circulation Approaching a Tipping Point?’, MIT colloquium, YouTube, 28 February 2022.

223 Greene et al., ‘Ubiquitous Acceleration’.

224 Kathryn L. Gunn, Stephen R. Rintoul, Matthew H. England and Melissa M. Bowen, ‘Recent Reduced Abyssal Overturning and Ventilation in the Australian Antarctic Basin’, *Nature Climate Change* (2023) 13: 537–44; Qian Li, Matthew H. England, Andrew McC. Hogg et al., ‘Abyssal Ocean Overturning Slowdown and Warming Driven by Antarctic Meltwater’, *Nature* (2023) 615: 841–7.

225 Guðfinna Aðalgeirsdóttir, Nathan Bindoff, Halldór Björnsson et al. ‘Open Letter by Climate Scientists to the Nordic Council of Ministers’, Reykjavik, October 2024.

226 Jens Terhaar, Linus Vogt and Nicholas P. Foukal, ‘Atlantic Overturning Inferred from Air-Sea Heat Fluxes Indicates No Decline since the 1960s’, *Nature Communications* (2025) 16: 1–17.

227 J. A. Baker, M. J. Bell, L. C. Jackson et al. ‘Continued Atlantic Overturning Circulation even under Climate Extremes’, *Nature* (2025) 638: 987–94.

228 For example, Stefan Rahmstorf, Michel Crucifix, Andrey Ganopalski et al., ‘Thermohaline Circulation Hysteresis: A Model Interpretation’, *Geophysical Research*

Letters (2005) 32: 1–5; Alley, *The Two-Mile*, 149–50; Scheffer, *Critical Transitions*, 159; Stocker and Marchal, 'Abrupt Climate'.

229 For example, René M. van Westen and Henk A. Dijkstra, 'Asymmetry of AMOC Hysteresis in a State-of-the-Art Global Climate Model', *Geophysical Research Letters* (2023) 50: 1–10.

230 O. Boucher, P. R. Halloran, E. J. Burke et al., 'Reversibility in an Earth System Model in Response to CO_2 Concentration Changes', *Environmental Research Letters* (2012) 7: 5; Wu et al., 'The Reversibility', 745; Masson-Delmotte et al., *Climate Change*, 622.

231 Masson-Delmotte et al., *Climate Change*, 634.

232 Kim Stanley Robinson, *Fifty Degrees Below* (New York: Harper Collins, 2005), 390.

233 Ibid., 480.

234 K. C. Armour, I. Eisenmann, E. Blanchard-Wrigglesworth et al., 'The Reversibility of Sea Ice Loss in a State-of-the-Art Climate Model', *Geophysical Research Letters* (2011) 38: 1–5; J. K. Ridley, J. A. Lowe and H. T. Hewitt, 'How Reversible is Sea Ice Loss?', *The Cryosphere* (2012) 6: 193–8.

235 Mika Rantanen, Alexey Yu. Karpechko, Antti Lipponen et al., 'The Arctic Has Warmed Nearly Four Times Faster than the Globe since 1979', *Communications Earth and Environment* (2022) 3: 1–9. For causes of the Arctic amplification other than the albedo feedback – the main one – see ibid.

236 R. W. Lindsay and J. Zhang, 'The Thinning of Arctic Sea Ice, 1988–2003: Have We Passed a Tipping Point?', *Journal of Climate* (2005) 18: 4879–94; Camille Hankel and Eli Tziperman, 'The Role of Atmospheric Feedbacks in Abrupt Winter Arctic Sea Ice Loss in Future Warming Scenarios', *Journal of Climate* (2021) 34: 4435–47.

237 Julienne Stroeve, Marika M. Holland, Walt Meier et al., 'Arctic Sea Ice Decline: Faster than Forecast', *Geophysical Research Letters* (2007) 34: 1–5; Quirin Scheiermeier, 'The New Face of the Arctic', *Nature* (2007) 446: 133–5; Wang et al., 'Mechanisms and Feedback', 43–4; ICCI, *Cryosphere 1.5°*, 19–21.

238 Maria-Vittoria Guarino, Louise C. Sime, David Schröder et al., 'Sea-Ice-Free Arctic during the Last Interglacial Supports Fast Future Loss', *Nature Climate Change* (2020) 10: 932; Yeon-Hee Kim, Seung-Ki Min, Nathan P. Gilett et al., 'Observationally-Constrained Projections of an Ice-Free Arctic Even under a Low Emission Scenario', *Nature Communications* (2023) 14: 1–8; Wang, 'Mechanisms and Impacts', 45; ICCI, *Cryosphere 1.5°*, 19–21; and cf. Marika M. Holland, Cecilia M. Bitz and Bruno Tremblay, 'Future Abrupt Reductions in the Summer Arctic Sea Ice', *Geophysical Research Letters* (2006) 33: 1–5. Indeed, the appearance of the first ice-free summer between 2030 and 2050 will happen under *any* conceivable emissions scenario, according to Kim et al., 'Observationally Constrained Projections'.

239 Michael Winton, 'Does the Arctic Sea Ice Have a Tipping Point?', *Geophysical Research Letters* (2006) 33: 5; Hankel and Tziperman, 'The Role of Atmospheric', 4436, 4445.

240 ICCI, *Cryosphere 1.5°*, 20.

241 S. J. Koenig, R. M. DeConto and D. Pollard, 'Impact of Reduced Arctic Sea Ice on Greenland Ice Sheet Variability in a Warmer Than Present Climate', *Geophysical Research Letters* (2014) 41: 3934–43.

242 Nico Wunderling, Matteo Willeit, Jonathan F. Donges and Ricarda Winkelmann, 'Global Warming Due to Loss of Large Ice Masses and Arctic Summer Ice', *Nature Communications* (2020) 11: 1–8. According to this study, the loss of albedo from the retreat of mountain glaciers, the Greenland and West Antarctic ice sheets would add another 0.3°C, although this would take a longer time to be realised than the practically immediate warming amplification from the Arctic. Put together, this feedback would

then imply that 1.5°C equals 2°C. See ibid. 'Global refrigerator': ICCI, *Cryosphere 1.5°*, 19. See further ICCI, *State of the Cryosphere 2022: Growing Losses, Global Impacts*, November 2022.

243 Sergey A. Zimov, Edward A. G. Schuur and F. Stuart Chapin III, 'Permafrost and the Global Carbon Budget', *Science* (2006) 312: 1612–13; C. L. Ping, J. D. Jastrow, M. T. Jorgenson et al., 'Permafrost Soils and Carbon Cycling', *SOIL* (2015) 1: 147–71; Edward A. G. Schuur, Benjamin W. Abbott, Roisin Commane et al., 'Permafrost and Climate Change: Carbon Cycle Feedbacks from the Warming Arctic', *Annual Reviews of Environment and Resources* (2022) 47: 347–8; Benjamin W. Abbott, 'A Race to Keep Permafrost Carbon Safely Frozen', *One Earth* (2023) 6: 1606. Sizable pockets of permafrost are also found in the Himalayas and on the margins of Antarctica.

244 For example, David M. Lawrence and Andrew G. Slater, 'A Projection of Severe Near-Surface Permafrost Degradation during the 21st Century', *Geophysical Research Letters* (2005) 32: 1–5; Koushik Dutta, E. A. G. Schuur, J. C. Neff and S. A. Zimov, 'Potential Carbon Release from Permafrost Soils of Northeastern Siberia', *Global Change Biology* (2006) 12: 2336–51; Kimberley R. Miner, Merritt R. Turetsky, Edward Malina et al., 'Permafrost Carbon Emissions in a Changing Arctic', *Nature Reviews Earth and Environment* (2022) 3: 56–7.

245 Jason A. Lowe and Daniel Bernie, 'The Impact of Earth System Feedbacks on Carbon Budgets and Climate Response', *Philosophical Transactions of the Royal Society A* (2018) 376: 1–13; Susan M. Natali, John P. Holdren, Brendan M. Rogers et al., 'Permafrost Carbon Feedbacks Threaten Global Climate Goals', *PNAS* (2021) 118: 1–3; Uta Kloenne, Alexander Nauels, Pam Pearson et al., 'Only Halving Emissions by 2030 Can Minimize Risks of Crossing Cryosphere Thresholds', *Nature Climate Change* (2023) 13: 11; Christina Schädel, Brendan M. Rogers, David M. Lawrence et al., 'Earth System Models Must Include Permafrost Carbon Processes', *Nature Climate Change* (2024) 14: 114–16; Zimov et al., 'Permafrost and the Global'; Schuur et al. 'Permafrost and Climate', 351.

246 Andrew H. MacDougall, Kirsten Zickfeld, Reto Knutti and H. Damon Matthews, 'Sensitivity of Carbon Budgets to Permafrost Carbon Feedbacks and Non-CO_2 Forcings', *Environmental Research Letters* (2015) 10: 1–10. Slightly lower figures are reported in Edward Comyn-Platt, Garry Hayman, Christ Huntingford et al., 'Carbon Budgets for 1.5 and 2°C Targets Lowered by Natural Wetland and Permafrost Feedbacks', *Nature Geoscience* (2018) 11: 568–73. Significantly higher figures are reported in T. Gasser, M. Kechiar, P. Ciais et al., 'Path-Dependent Reductions in CO_2 Emission Budgets Caused by Permafrost Carbon Release', *Nature Geoscience* (2018) 11: 830–5.

247 Andrew H. MacDougall, 'Reversing Climate Warming by Artificial Atmospheric Carbon-Dioxide Removal: Can a Holocene-Like Climate Be Reversed?', *Geophysical Research Letters* (2013) 40: 5480–5; MacDougall et al., 'Sensitivity of Carbon', 7; Natali et al., 'Permafrost Carbon', 2.

248 On such regional loops, see further A. David McGuire, F. S. Chapin III, John E. Walsh and Christian Wirth, 'Integrated Regional Changes in Arctic Climate Feedbacks: Implications for the Global Climate System', *Annual Review of Environmental Resources* (2006) 31: 61–91.

249 Benjamin W. Abbott, Michael Brown, Joanna C. Carey et al., 'We Must Stop Fossil Fuel Emissions to Protect Permafrost Ecosystems', *Frontiers in Environmental Science* (2022) 10: 2.

250 Katey Walter Anthony, Thomas Schneider von Deimling, Ingmar Nitze et al., '21st-Century Modeled Permafrost Carbon Emissions Accelerated by Abrupt Thaw beneath

Lakes', *Nature Communications* (2018) 9: 2; Merritt R. Turetsky, Benjamin W. Abbott, Miriam C. Jones et al., 'Carbon Release through Abrupt Permafrost Thaw', *Nature Geoscience* (2020) 13: 138; Natali et al., 'Permafrost Carbon', 1; Miner et al., 'Permafrost Carbon', 55.

251 E. A. G. Schuur, A. D. McGuire, G. Schädel et al., 'Climate Change and the Permafrost Carbon Feedback', *Nature* (2015) 520: 171.

252 Ping et al., 'Permafrost Soils', 151; Schuur et al., 'Permafrost and Climate', 350–1; Anthony et al., '21st-Century Modeled', 2, 4, 7; Miner et al., 'Permafrost Carbon', 55–6; Turetsky et al., 'Carbon Release', 138, 141; ICCI, *Cryosphere 1.5°*, 15; Wang et al., 'Mechanisms and Impacts', 22–3. On the methane factor, see, for example, K. M. Walter, S. A. Zimov, J. P. Chanton et al., 'Methane Bubbling from Siberian Thaw Lakes as a Positive Feedback to Global Warming', *Nature* (2006) 443: 71–5; Elizabeth M. Herndon, 'Permafrost Slowly Exhales Methane', *Nature Climate Change* (2018) 8: 273–4; Christian Knoblauch, Christian Beer, Susanne Liebner et al., 'Methane Production as Key to the Greenhouse Gas Budget of Thawing Permafrost', *Nature Climate Change* (2018) 8: 309–12.

253 See for example, Vasily Bogoyavlensky, Igor Bogoyavlensky, Roman Nikonov et al., 'New Catastrophic Gas Blowout and Giant Crater on the Yamal Peninsula in 2020: Results of the Expedition and Data Processing', *Geosciences* (2021) 11: 1–21.

254 Philipp de Vrese and Victor Brovkin, 'Timescales of the Permafrost Carbon Cycle and Legacy Effects of Temperature Overshoot', *Nature Communications* (2021) 12: 8; Antony et al., '21st-Century', 4; Miner et al., 'Permafrost Carbon', 58; Naftali et al., 'Permafrost Carbon', 1; Wang et al., 'Mechanisms and Impacts', 20. As of the early 2020s, wildfires igniting permafrost thaw were also omitted from models and projections.

255 Anthony, '21st-Century Modeled', 4; Natali, 'Permafrost Carbon', 2, 3; Turetsky et al., 'Carbon Release', 139, 141.

256 Schädel et al., 'Earth System', 115.

257 Ibid.

258 Antony et al., '21st-Century Modeled', 7; de Vrese and Brovkin, 'Timescale of the Permafrost', 7.

259 Armstrong McKay et al., 'Exceeding 1.5°C', 5.

260 de Vrese and Brovkin, 'Timescales of the Permafrost', 8; Richard E. Fewster, Paul J. Morris, Ruza F. Ivanovic et al., 'Imminent Loss of Climate Space for Permafrost Peatlands in Europe and Western Siberia', *Nature Climate Change* (2022) 12: 373–9.

261 Jorgen Randers and Ulrich Goluke, 'An Earth System Model Shows Self-Sustained Thawing of Permafrost Even if All Man-Made Emissions Stop in 2020', *Scientific Reports* (2020) 10: 1–8.

262 Cf. Schuur et al., 'Permafrost and Climate', 352; Abbott et al., 'We Must', 4, 6.

263 de Vrese and Brovkin, 'Timescales of the Permafrost', 1, 6, 8; cf. Natali et al., 'Permafrost Carbon', 1.

264 Jasmine E. Saros, Václava Hazuková, Robert M. Northington et al., 'Abrupt Transformation of West Greenland Lakes Following Compound Climate Extremes Associated with Atmospheric Rivers', *PNAS* (2025) 122: 4.

265 See further ibid.

266 As argued in Abbott et al., 'We Must', 7.

267 Randers and Goluke, 'An Earth', 1, 8. For this particular purpose of geoengineering, see further Yating Chen, Aobo Liu and John C. Moore, 'Mitigation of Arctic Permafrost Carbon Loss through Stratospheric Aerosol Geoengineering', *Nature Communications* (2020) 11: 1–10.

268 The classic paper describing these mechanisms is Eneas Salati, Atillio Dall'Olio, Eiichi Matsui and Joel R. Gat, 'Recycling of Water in the Amazon Basin: An Isotopic Study', *Water Resources Research* (1979) 15: 1250–8. Cf. for example, Eneas Salati and Peter B. Vose, 'Amazon Basin: A System in Equilibrium', *Science* (1984) 225: 129–38. For updated studies, see Arie Staal, Obbe A. Tuinenburg, Joyce H. C. Bosmans et al., 'Forest-Rainfall Cascades Buffer against Drought across the Amazon', *Nature Climate Change* (2018) 8: 539–43; Arie Staal, Ingo Fetzer, Lan Wang-Erlandsson et al., 'Hysteresis of Tropical Forests in the 21st Century', *Nature Communications* (2020) 11: 1–8.

269 Sharon A. Cowling, Richard A. Betts, Peter M. Cox et al., 'Contrasting Simulated Past and Future Responses of the Amazonian Forest to Atmospheric Change', *Philosophical Transactions of the Royal Society B* (2004) 359: 539–47; P. M. Cox, R. A. Betts, M. Collins et al., 'Amazonian Forest Dieback under Climate-Carbon Cycle Projections for the 21st Century', *Theoretical and Applied Climatology* (2004) 78: 137–56; L. R. Hutyra, J. W. Munger, C. A. Nobre et al., 'Climatic Variability and Vegetation Vulnerability in Amazonia', *Geophysical Research Letters* (2005) 32: 1–4; Luis F. Salazar, Carlos A. Nobre and Marcos D. Oyama, 'Climate Change Consequences on the Biome Distribution in Tropical South America', *Geophysical Research Letters* (2007) 34: 1–6; Marina Hirota, Milena Holmgren, Egbert H. Van Nes and Marten Scheffer, 'Global Resilience of Tropical Forest and Savanna to Critical Transitions', *Science* (2011) 334: 232–4; Carlos A. Nobre, Gilvan Sampaio, Laura S. Borma et al., 'Land-Use and Climate Change Risks in the Amazon and the Need for a Novel Sustainable Development Paradigm', *PNAS* (2016) 113: 10763; Ignacio Amigo, 'The Amazon's Fragile Future', *Nature* (2020) 578: 505–6; Xiyan Xu, Xiaoyan Zhang, William J. Riley et al., 'Deforestation Triggering Irreversible Transition in Amazon Hydrological Cycle', *Environmental Research Letters* (2022) 17: 1–2; Nils Bochow and Niklas Boers, 'The South American Monsoon Approaches a Critical Transition in Response to Deforestation', *Science Advances* (2023) 9: 3, 8; Scheffer, *Critical Transitions*, 220.

270 Bernardo M. Flores, Encarni Montoya, Boris Sakschewski et al., 'Critical Transitions in the Amazon Forest System', *Nature* (2024) 626: 556.

271 Cf. Christian Skirke, 'After Auschwitz', in Peter E. Gordon, Espen Hammer and Max Pensky (eds), *A Companion to Adorno* (Hoboken: Wiley Blackwell, 2020), 567–83.

272 Flores et al., 'Critical Transitions', 555. One way this end would materialise: in the absence of the rainforest, levels of heat which human bodies cannot survive. Beatriz Fátima Alves de Oliviera, Marcus J. Bottino, Paulo Nobre and Carlos A. Nobre, 'Deforestation and Climate Change Are Projected to Increase Heat Stress Risk in the Brazilian Amazon', *Communications Earth and Environment* (2021) 2: 1–8.

273 James S. Albert, Ana C. Carnaval, Suzette G. A. Flantua et al., 'Human Impacts Outpace Natural Processes in the Amazon', *Science* (2023) 379: 1.

274 Ibid., 3.

275 Staal et al., 'Forest-Rainfall Cascades', 541.

276 Nobre et al., 'Land-Use and Climate', 10760–1; cf. Daniel Grossman, 'Trouble in the Amazon', *Nature* (2023) 620: 715; Flores et al., 'Critical Transitions', 557.

277 Liana Oighenstein Anderson, Germano Ribeiro Neto, Ana Paula Cunha et al., 'Vulnerability of Amazonian Forests to Repeated Droughts', *Philosophical Transactions of the Royal Society B* (2018) 373: 1–13; Chris A. Boulton, Timothy M. Lenton and Niklas Boers, 'Pronounced Loss of Amazon Rainforest Resilience Since the Early 2000s', *Nature Climate Change* (2022) 12: 277; Ben Clarke, Clair Barnes, Regina Rodrigues et al., 'Climate Change, Not El Niño, Main Driver of Exceptional Drought in

Highly Vulnerable Amazon Basin', *World Weather Attribution*, 24 January 2024, 2–4; Albert et al., 'Human Impacts', 3.

278 Salvador Pueyo, Paulo Maurício Lima de Alcentrasto Graça, Reinaldo Imbrozio Barbosa et al., 'Testing for Criticality in Ecosystem Dynamics: The Case of Amazonian Rainforest and Savanna Fire', *Ecology Letters* (2010) 13: 793–802; Xiyan Xu, Genso Jia, Xiaoyan Zhang et al., 'Climate Regime Shift and Forest Loss Amplify Fire in Amazonian Forests', *Global Change Biology* (2020) 26: 5874–85.

279 Matthew W. Jones, John T. Abatzoglu, Sander Veraverbeke et al., 'Global and Regional Trends and Drivers of Fire under Climate Change', *Reviews of Geophysics* (2022) 60: 17.

280 Bernardo M. Flores and Milena Holmgren, 'White-Sand Savannas Expand at the Core of the Amazon after Forest Wildfires', *Ecosystems* (2021) 24: 1624–37.

281 David M. Lapola, Patricia Pinho, Jos Barlow et al., 'The Drivers and Impacts of Amazon Forest Degradation', *Science* (2023) 379: 3; Pueyo et al., 'Testing for Criticality', 793, 800; Boulton et al., 'Pronounced Loss', 271.

282 Markus Drüke, Boris Sakschewski, Werner von Bloh et al., 'Fire May Prevent Future Amazon Forest Recovery after Large-Scale Deforestation', *Communications Earth and Environment* (2023) 4: 1–9; Staal et al., 'Hysteresis of Tropical'; Wang et al., 'Mechanisms and Impacts', 42; Flores et al., 'Critical Transitions', 561; also cf. the earlier study by Egbert H. Van Nes, Marina Hirota, Milena Holmgren and Marten Scheffer, 'Tipping Points in Tropical Tree Cover: Linking Theory to Data', *Global Change Biology* (2014) 20: 1016–21.

283 For example, Salati et al., 'Recycling of Water', 1250, 1258; Salati and Vose, 'Amazon Basin', 130, 136.

284 Xu et al., 'Deforestation Triggering'; and for degradation of the forest – distinct from deforestation in that trees are still standing but are thinned out or unhealthy or otherwise degraded – see Lapola et al., 'The Drivers and Impacts'.

285 Simon Willcock, Gregory S. Cooper, John Addy and John A. Dearing, 'Earlier Collapse of Anthropocene Ecosystems Driven by Multiple Faster and Noisier Drivers', *Nature Sustainability* (2023) 6: 1331–42. For interaction between many stressors in the oceans, see Christopher Heinze, Thorsten Blenckner, Helena Martins et al., 'The Quiet Crossing of Ocean Tipping Points', *PNAS* (2021) 118: 1–9.

286 For example, Viviana Zalles, Matthew C. Hansen, Peter V. Potapov et al., 'Rapid Expansion of Human Impact on Natural Land in South America Since 1985', *Science Advances* (2021) 7: 1–11; Albert et al., 'Human Impacts', 2.

287 See Malm and the Zetkin Collective, *White Skin*, 206–19, 537–8; and for the effects of deforestation through burning, Jones et al., 'Global and Regional', 36–7.

288 Arie Staal, Stefan C. Dekker, Marina Hirota and Egbert H. van Nes, 'Synergistic Effects of Drought and Deforestation on the Resilience of the South-Eastern Amazon Rainforest', *Ecological Complexity* (2015) 22: 65–75.

289 Carlos Afonso Nobre and Laura De Simona Borma, '"Tipping Points" for the Amazon Forest', *Current Opinion in Environmental Sustainability* (2009) 1: 28–36; Nobre et al., 'Land-Use and Climate', 10759, 10764. The 4°C figure was included in Lenton et al., 'Tipping Elements', 1790. Cf. the retrospect in Boulton et al., 'Pronounced Loss', 271.

290 Thomas E. Lovejoy and Carlos Nobre, 'Amazon Tipping Point', *Science Advances* (2018) 4: 1. Remarkably, Nobre was the lead author of 'Land-Use and Climate', which repeated the formula 40 per cent or four degrees in 2016; only two years later, he put his name under a slashing of the former figure by nearly half.

291 Albert et al., 'Human Impacts', 1.

292 Meghie Rodrigues, ‘The Amazon’s Record-Setting Drought: How Bad Will It Be?’, *Nature* (2023) 623: 675. Or, ‘more than 20%’: Bochow and Boers, ‘The South American’, 1. Cf. Wang et al., ‘Mechanisms and Impacts’, 38. Using different calculations, one study claimed that 13 to 15 per cent of the original forest has been lost – and that the ‘safe boundary’ against tipping sits at 10 per cent, ‘which requires ending large-scale deforestation and restoring at least 5% of the biome.’ Flores et al., ‘Critical Transitions’, 560.

293 The Panel assigned ‘low probability’ to the crossing of a tipping point before the end of the century: Masson-Delmotte et al., *Climate Change*, 739, 1059.

294 Flores et al., ‘Critical Transitions’, 559.

295 Bochow and Boers, ‘The South American’, 1. For contemporary research on early warning signals, see Vasilis Dakos, Chris A. Boulton, Joshua E. Baxton et al., ‘Tipping Point Detection and Early Warnings in Climate, Ecological, and Human Systems’, *Earth System Dynamics* (2024) 15: 1117–35.

296 Thomas E. Lovejoy and Carlos Nobre, ‘Amazon Tipping Point: Last Chance for Action’, *Science Advances* (2019) 5: 2; Boulton et al., ‘Pronounced Loss’, 271; Albert et al., ‘Human Impacts’, 1; Karina Lima in Rodrigues, ‘The Amazon’s Record-Setting’, 676. Or, ‘the Amazon hydrological system is approaching an irreversible transition’. Xu et al., ‘Deforestation Triggering’, 8. Or, there are ‘characteristic precursor signals to the nearing of a critical transition’. Bochow and Boers, ‘The South American’, 1.

297 Heterogeneity in space can thus imply lack of synchronicity in time as ecosystems such as the Amazon approach their nodal lines: see Scheffer, *Critical Transitions*, 29–30, 86–90. For a fine-grained analysis of the Amazon, see Flores et al., ‘Critical Transitions’, 558–9.

298 Nico Wunderling, Arie Staal, Boris Sakschewski et al., ‘Recurrent Droughts Increase Risk of Cascading Tipping Events by Outpacing Adaptive Capacities in the Amazon Rainforest’, *PNAS* (2022) 119: 1–11; Timothy M. Lenton, Jesse F. Abrams, Annett Bartsch et al., ‘Remotely Sensing Potential Climate Change Tipping Points across Scales’, *Nature Communications* (2024) 15: 3; Flores et al., ‘Critical Transitions’, 558–9; Bochow and Boers, ‘The South American’, 3–5, 8.

299 Luciana V. Gatti, Luana S. Basso, John B. Miller et al., ‘Amazonia as a Carbon Source Linked to Deforestation and Climate Change’, *Nature* (2021) 595: 388–93.

300 Albert et al., ‘Human Impacts’, 1, 3. Cf. Lapola et al., ‘The Drivers and Impacts’, 4–5.

301 Martin J. P. Sullivan, Simon L. Lewis, Kofi Affum-Baffoe et al., ‘Long-Term Thermal Sensitivity of Earth’s Tropical Forests’, *Science* (2020) 368: 1–6; Guilherme Mataveli, Matthew W. Jones, Rachel Carmenta et al., ‘Deforestation Falls but Rise of Wildfires Continues Degrading Brazilian Amazon Forests’, *Global Change Biology* (2024) 30: 1–3; Flores et al., ‘Critical Transitions’, 556, 559; Wang et al., ‘Mechanisms and Impacts’, 40. On Lula’s gestures, see for example, Tom Phillips, ‘Brazilian President Lula Pledges “New Amazon Dream” at Rainforest Summit’, *Guardian*, 8 August 2023; but cf. Jonathan Watts, ‘Optimism Dries Up in Amazon as Lula Drifts from Climate Priorities’, *Guardian*, 25 January 2024.

302 Wunderling et al., ‘Recurrent Drought’, 2; cf. Bochow and Boers, ‘The South American’, 3. There might also, however, be flooding during the wet season, with other kinds of devastating effects: see Daniel Grossman, ‘A River in Flux’, *Nature* (2024) 383: 694–7.

303 Delphine Clara Zemp, Carl-Friedrich Schleussner, Henrique M. J. Barbossa et al., ‘Self-Amplified Amazon Forest Loss Due to Vegetation-Atmosphere Feedbacks’, *Nature Communications* (2017) 8: 1–10. Warming is already, as we have seen, the main driver of the droughts: cf. also Arie Staal, Bernardo M. Flores, Ana Paula D. Aguiar et al.,

‘Feedback between Drought and Deforestation in the Amazon’, *Environmental Research Letters* (2020) 15: 1–10.

304 Rodrigues, ‘The Amazon’s Record-Setting’; Grossman, ‘A River in Flux’; Ana Ionova and Manuela Andreoni, ‘A Severe Drought Pushes an Imperiled Amazon to the Brink’, *New York Times*, 17 October 2023; Ana Ionova and Livia Albeck-Ripka, ‘A Lake Turned to a Hot “Soup”. Then the River Dolphins Died’, *New York Times*, 4 October 2023; Stephanie Hegarty, ‘Amazon Drought: “We’ve Never Seen Anything Like This”’, BBC, 26 December 2023; Ayan Fleischmann in Grossman, ‘A River in Flux’, 696.

305 Clarke et al., ‘Climate Change’. Cf. Grossman, ‘A River in Flux’, 695.

306 For example, Alex Cuadros, ‘Has the Amazon Reached Its “Tipping Point”?’, *New York Times*, 4 January 2023; Hegarty, ‘Amazon Drought’.

307 Rupert Seidl, Dominik Thom, Markus Kautz et al., ‘Forest Disturbance under Climate Change’, *Nature Climate Change* (2017) 7: 395–402.

308 For example, Barbara Drossel, ‘Self-Organized Criticality and Synchronization in a Forest-Fire Model’, *Physical Review Letters* (1996) 76: 936–9; Bruce D. Malamud, Gleb Morein and Donald L. Turcotte, ‘Forest Fires: An Example of Self-Organized Critical Behavior’, *Science* (1998) 281: 1840–2; Gregory Bunk, ‘Understanding Self-Organized Criticality as a Statistical Process’, *Complexity* (2000) 5: 26–33; Proshun Sinha-Ray and Henrik Jeldtoft Jensen, ‘Forest-Fire Models as a Bridge between Different Paradigms in Self-Organized Criticality’, *Physical Review E* (2000) 62: 3215–18; Mercedes Pascual and Frédéric Guichard, ‘Criticality and Disturbance in Spatial Ecological Systems’, *Trends in Ecology and Evolution* (2004) 20: 87–95; Salvador Pueyo, ‘Self-Organised Criticality and the Response of Wildland Fires to Climate Change’, *Climatic Change* (2007) 82: 131–61; Jensen, *Self-Organized*, 65–8; Buchanan, *Ubiquity*, 79–91; Scheffer, *Critical Transitions*, 58–9. Note that the forest-fire model of self-organised criticality focused on how the growth of forests in itself makes them prone to outbreaks of fire: dense stacks of vegetation are more combustible than scattered sprigs. There will then a be a power-law distribution of fires, like the slides in the pile: many small ones, a few major disasters. Here, again, the theory of self-organised criticality is instead adapted for the study of the *historical process* of global warming, with the overaccumulation of heat due to CO_2 emissions entering the forest ecosystems and pushing them into states of criticality.

309 Christopher P. O. Reyer, Niels Brouwers, Anja Rammig et al., ‘Forest Resilience and Tipping Points at Different Spatio-Temporal Scales: Approaches and Challenges’, *Journal of Ecology* (2015) 103: 5–15; Dominik Thom, ‘Natural Disturbances as Drivers of Tipping Points in Forest Ecosystems under Climate Change: Implications for Adaptive Management’, *Forestry* (2023) 96: 305–15. On the already disastrous effects of heat and drought on the world’s forests, see William M. Hammond, A. Park Williams, John T. Abatzoglou et al., ‘Global Field Observations of Tree Die-Off Reveal Hotter-Drought Fingerprint for Earth’s Forests’, *Nature Communications* (2022) 13: 1–11.

310 Joe Sutton, Taylor Ward and Zoe Sottile, ‘Canadian Wildfire Smoke Reaches Europe as Canada Reports Its Worst Fire Season on Record’, *CNN*, 27 June 2023.

311 Jones et al., ‘Global and Regional’; Matthew W. Jones, Sander Veraverbeke, Niels Andela et al., ‘Global Rise in Forest Fire Emissions Linked to Climate Change in the Extratropics’, *Science* (2024) 386: 1–12. The main exception has been the savannas of Africa: Jones et al., ‘Global and Regional’, 17–18.

312 Jones et al., ‘Global and Regional’, 56–7.

313 Ibid., 2; Rachael H. Nolan, Luke Collins, Andy Leigh et al., ‘Limits to Post-Fire Vegetation Recovery under Climate Change’, *Plant, Cell and Environment* (2021) 44: 3471–89.

314 Enric Batllori, Francisco Lloret, Tuomas Aakala et al., ‘Forest and Woodland Replacement Patterns Following Drought-Related Mortality’, *PNAS* (2020) 117: 29720–9.

315 Marten Scheffer, Marina Hirota, Milena Holmgren et al., ‘Thresholds for Boreal Biome Transitions’, *PNAS* (2012) 109: 21384.

316 Ibid., 21384–7; Arden Burrell, Elena Kukavskaya, Robert Baxter et al., ‘Post-Fire Recruitment Failure as a Driver of Forest to Non-Forest Ecosystem Shifts in Boreal Regions’, in Josep G. Canadell and Robert B. Jackson (eds), *Ecosystem Collapse and Climate Change* (Cham: Springer, 2021), 69–100; and cf. Ronny Rotbarth, Egberth H. van Nes, Marten Scheffer and Milena Holmgren, ‘Boreal Forests Are Heading for an Open State’, *PNAS* (2025) 122: 1–7.

317 Mukund Palat Rao, Nicole K. Davi, Troy S. Magney et al., ‘Approaching a Thermal Tipping Point in the Eurasian Boreal Forest at its Southern Margin’, *Communications Earth and Environment* (2023) 4: 7, 8.

318 Ibid., 2. At least one study indicates that a dynamic shift of more heat and more drought occurred in the boreal forests of western Eurasia in the 1990s, presaging a tipping point for the biome: Wolfgang Buermann, Bikash Parida, Martin Jung et al., ‘Recent Shift in Eurasian Boreal Forest Greening Response May Be Associated with Warmer and Drier Summers’, *Geophysical Research Letters* (2014) 41: 1995–2002. It should be noted that a flipside of this process is that boreal forests migrate northwards in a warming world. But this alters the albedo: taiga is darker than tundra. Unfortunately, the albedo effect is here so large as to cancel out the beneficial effect on the earth’s energy balance from forests sequestering more carbon on their northern frontiers. In other words, northward dispersal will heat up the planet further. See for example, Richard A. Betts, ‘Offset of the Potential Carbon Sink from Boreal Forestation by Decreases in Surface Albedo’, *Nature* (2000) 408: 187–90; Wang et al., ‘Mechanisms and Impacts’, 26–8.

319 Anna-Maria Virkkala, Brendan Rogers, Jennifer Watts et al., ‘Wildfires Offset the Increasing but Spatially Heterogeneous Arctic-Boreal CO_2 Uptake’, *Nature Climate Change* (2025) 15: 188–95.

320 Jennifer Baltzer, ‘Boreal Forests Have Reached a Tipping Point Already’, *One Earth* (2023) 6: 1607. The emissions from fires in boreal North America in 2023 were ten times larger than in an average year between 2000 and 2020: Lili Liang, Shijing Liang and Zhenzhong Zeng, ‘Extreme Climate Sparks Record Boreal Wildfires and Carbon Surge in 2023’, *The Innovation* (2024) 5: 1.

321 Peter B. Reich, Raimundo Bermudez, Rebecca A. Montgomery et al., ‘Even Modest Climate Change May Lead to Major Transitions in Boreal Forests’, *Nature* (2022) 608: 540–5; cf. Renato K. Braghiere, Joshua B. Fisher, Kimberley R. Miner et al., ‘Tipping Point in North American Arctic-Boreal Carbon Sink Persists in New Generation Earth System Models Despite Reduced Uncertainty’, *Environmental Research Letters* (2023) 18: 1–16.

322 Katharina Albrich, Werner Rammer and Rupert Seidl, ‘Climate Change Causes Critical Transitions and Irreversible Alterations of Mountain Forests’, *Global Change Biology* (2020) 26: 4013–27.

323 Vanda Acácio, Milena Holmgren, Francisco Rego et al., ‘Are Drought and Wildfires Turning Mediterranean Cork Oak Forests into Persistent Shrublands?’, *Agroforestry Systems* (2009) 76: 389–400.

324 Pierre Giresse, Jean Maley and Alex Chepstow-Lusty, ‘A Focus on the Last 1000 Years of Natural Environmental Changes in the Tropical Rainforests of West and Central Africa: Can We Detect Anthropogenic Disturbances?’, *Global and Planetary Change* (2023) 220: 23; Wannes Hubau, Simon L. Lewis, Oliver L. Phillips et al.,

‘Asynchronous Carbon Sink Saturation in African and Amazonian Tropical Forests’, *Nature* (2020) 579: 80–7; Xun Jiang, Ronald Albright, Ellen Creecy et al., ‘Congo Basin Rainforest Is a Net Carbon Source During the Dry Season’, *Earth and Space Science* (2023) 10: 1–12. See also, for example, David Bauman, Claire Fortunel, Guillaume Delhaye et al., ‘Tropical Tree Mortality Has Increased with Rising Atmospheric Water Stress’, *Nature* (2022) 608: 528–33.

325 N. Saintilan, N. S. Khan, E. Ashe et al., ‘Thresholds of Mangrove Survival under Rapid Sea Level Rise’, *Science* (2020) 368: 1118–21. Mangrove forests located in high tidal ranges may survive for longer.

326 Juan Rocha, Gary Peterson, Örjan Bodin and Simon Lewis, ‘Cascading Regime Shifts within and across Scales’, *Science* (2018) 362: 1–5; Nico Wunderling, Jonathan F. Donges, Jürgen Kurths and Ricarda Winkelmann, ‘Interacting Tipping Elements Increase Risk of Climate Domino Effects under Global Warming’, *Earth System Dynamics* (2021) 12: 601–19; Ann Kristin Klose, Nico Wunderling, Ricarda Winkelmann and Jonathan F. Donges, ‘What Do We Mean, “Tipping Cascade”?’, *Environmental Research Letters* (2021) 16: 1–11; Nico Wunderling, Anna S. von der Heydt, Yevgeny Aksenov et al. ‘Climate Tipping Point Interactions and Cascades: A Review’, *Earth System Dynamics* (2024) 15: 41–74; Scheffer, *Critical Transitions*, 87.

327 Wunderling et al., ‘Interacting Tipping’, 613; Rosser et al., ‘Polar Ice’, 3, 6; Klose et al., ‘Rate-Induced Tipping’.

328 J. L. Thomas, C. M. Polashenski, A. J. Soja et al. ‘Quantifying Black Carbon Deposition over the Greenland Ice Sheet from Forest Fires in Canada’, *Geophysical Research Letters* (2017) 44: 7965–74; S. McKenzie Skiles, Mark Flanner, Joseph M. Cook et al., ‘Radiative Forcing by Light-Absorbing Particles in Snow’, *Nature Climate Change* (2018) 8: 964–71.

329 Wunderling et al., ‘Interacting Tipping’, 607; Mark M. Dekker, Anna S. von der Heydt and Henk A. Dijkstra, ‘Cascading Transitions in the Climate System’, *Earth System Dynamics* (2018) 9: 1243.

330 Wunderling et al., ‘Interacting Tipping’, 613.

331 Teng Liu, Dean Chen, Lan Yang et al., ‘Teleconnections among Tipping Elements in the Earth System’, *Nature Climate Change* (2023) 13: 67–74.

332 Wunderling et al., ‘Interacting Tipping’, 607; on reciprocating cascades, cf. Rocha et al., ‘Cascading Regime’, 1; Klose et al., ‘What Do’, 7.

333 Steffen et al., ‘Trajectories of the Earth’. Cf. Wang et al., ‘Mechanisms and Impacts’, 46–54; Wunderling et al., ‘Interacting Tipping’, 602; Lenton et al., ‘Climate Tipping’, 594–5; Kemp, ‘Climate Endgame’.

334 For example, Buchanan, *Ubiquity*; Scheffer, *Critical Transitions*, 61; Thomas Kron and Thomas Grund, ‘Society as a Self-Organized Critical System’, *Cybernetics and Human Knowing* (2009) 16: 65–6, 75–9.

335 Vladimir Ilyich Lenin, ‘Conspectus of Hegel’s *Science of Logic*: Book I (The Doctrine of Being)’, in *Lenin Collected Works: Volume 38, Philosophical Notebooks 1895–1916*, Marxists Internet Archive; see further Daniel Bensaïd, ‘“Leaps! Leaps! Leaps!”, in Sebastian Budgen, Stathis Kouvelakis and Slavoj Žižek (eds), *Lenin Reloaded: Towards a Politics of Truth* (Durham: Duke University Press, 2007), 159; Nathan Coombs, ‘Did Lenin Refound Marxist Dialectics in 1914?’, *The European Legacy* (2016) 21: 9. The most detailed analysis of Lenin reading Hegel at this moment, however, is Kevin B. Anderson, *Lenin, Hegel, and Western Marxism: A Critical Study* (Chicago: Haymarket, 2023).

336 Stathis Kouvelakis, ‘Lenin as Reader of Hegel: Hypotheses for a Reading of Lenin’s Notebooks on Hegel’s *The Science of Logic*’, in Budgen et al., *Lenin Reloaded*, 167.

337 Vladimir Ilyich Lenin, ‘Karl Marx: A Brief Biographical Sketch with an Exposition of Marxism’, in *Lenin Collected Works: Volume 21, August 1914–December 1915*, Marxists Internet Archive (emphasis in original).

338 Kouvelakis, ‘Lenin as Reader’, 174.

339 Lenin, ‘Karl Marx’ (parenthesis in the original removed). The revolution-catastrophe couplet is a theme – but arguably an underdeveloped one – in Paul Le Blanc, *Lenin: Responding to Catastrophe, Forging Revolution* (London: Pluto, 2023). It is a sign of his uniqueness among politicians in the global North – not only the most effective leader of a left-wing party, but a consummate intellectual in his own right – that Jean-Luc Mélenchon draws on the science of self-organised criticality to conceptualise revolutions, while also considering tipping points in the climate system, in *Now, the People! Revolution in the Twenty-First Century* (London: Verso, 2025), 81–2, 171–5.

340 Kevin B. Anderson desperately tries to drive a wedge between the truly Hegelian Lenin of 1914 and the insufficiently Hegelian Engels. Thus, after quoting this same passage from the encyclopaedia entry, he claims that Lenin here stressed, ‘as against Engels and Plekhanov, that dialectics is a theory of development through leaps, breaks, and negations rather than a variety of scientific evolutionism, as Engels’ writings had suggested’. Anderson, *Lenin, Hegel*, 83. This reading of Engels has no evidentiary support, as the quotations from him adduced above would suffice to show. Anderson himself seems aware of this later in his text, when he comments on Engels’s recycling of the Hegelian dialectics – the leaps and breaks in particular – in *Anti-Dühring*. But Anderson is one of those Marxists who seem inconvenienced or embarrassed by Engels’s grounding of the dialectics in natural science and insistence on the operation of the ‘laws’ in nature. Engels is here supposedly inferior to Lenin because he emphasised the presence of leaps and breaks in natural processes. See ibid., for example, 101–2, 175. Nathan Coombs has convincingly rebutted the hypothesis that Lenin broke with Engels by returning to a more purely, more revolutionary Hegelian dialectics in 1914. Coombs, ‘Did Lenin’. If there was a break, it was in the novel sensitivity to catastrophe (a category not of interest for Anderson).

341 On the two former themes, cf. Foster, *The Return*, 269, 283–6. But it is thus an error to associate breaks and leaps in nature exclusively or even primarily with ‘emergence’, or the appearance of novel, higher-level properties, as Foster does in ibid., 222, 241, 251. What we are concerned with here is rather *sub*mergence, ‘the *loss* of higher-level properties’, ‘the (partial or total) dismantling of systems of some kind’. Mario Bunge, *Emergence and Convergence: Qualitative Novelty and the Unity of Knowledge* (Toronto: University of Toronto Press, 2003), 31 (emphasis added).

342 The closest approximation are allusions to the destructive potential of quantitative change becoming qualitative, as when Hegel speaks of an existence being attacked from the side of quantum and laid low. ‘It is the *cunning* of the concept that it would seize on an existence from this side where its quality does not seem to come into play – and it does it so well that the aggrandisement of a State or of a patrimony, etc., which will bring about the misfortune of the State or the owner, even appears at first to be their good fortune.’ Hegel, *The Science*, 291 (emphasis in original).

343 Kangal, *Friedrich Engels*, 112.

344 See further, for example, Bensaïd, ‘“Leaps!”’, 156–9; Andreas Malm, *Corona, Climate, Chronic Emergency: War Communism in the Twenty-First Century* (London: Verso, 2020), 125–8.

345 See further Malm and Carton, *Overshoot*.

346 Quoted in Foster, *The Return*, 16, 230, 255. The proof is not the least constituted by the two realms of society and nature being thrown into one spiral-form development – in

other words, the dialectics does not apply to one or the other, but precisely to both. Society too will be swept up in this 'generalised apocalypse', attesting to the interpenetration of the opposites in one material world.

347 The dispute was famously inaugurated by Georg Lukács in the sixth footnote to *History and Class Consciousness*, in which he removed nature from the remit of dialectics, on the grounds that 'the crucial determinants of dialectics – the interaction of subject and object, the unity of theory and practice, the historical changes in the reality underlying the categories as the root cause of changes in thought, etc. – are absent from our knowledge of nature'. Georg Lukács, *History and Class Consciousness* (Cambridge, MA: MIT Press, 1971 [1923]), 24. See further Foster, *The Return*, 17–20 (and indeed the rest of this work); Kangal, *Friedrich Engels*, 43–79; Barot, 'Review of *Sciences*'. This argument – which, Lukács, also famously, later retracted – made the agency of a subject endowed with a mind an absolute criterion for dialectics. It thereby privileged the idealist dimension of Hegelian dialectics, at the expense of, for instance, quantity-quality leaps. The argument was also tautological: nature cannot fall within the remit of dialectics, since that which defines society in contradistinction to nature – people with minds – is absent from it. Critics like Foster and Kangal are right to turn the tables on the sixth footnote. See, for example, Kangal, *Friedrich Engels*, 201–1. (But note that seeing dialectics at work in both nature and society has nothing to do with a hybridist collapse of the distinction between them, a proposition that would have been unintelligible to Marx, Engels, Lenin). Foster, however, exaggerates the foundational importance for the Frankfurt School of the sixth footnote and the exclusion of nature from dialectics: see for example, Foster, *The Return*, 17–18. No Marxists more assiduously followed Lenin's lead in focusing on the category of catastrophe, in both society and nature, than Benjamin and Adorno. For an excellent rebuttal of Foster's charges against the Frankfurt School and a validation of its insights, see Carl Cassegård, *Toward a Critical Theory of Nature: Capital, Ecology, and Dialectics* (London: Bloomsbury, 2021).

348 As for extreme weather events, droughts and downpours are both becoming more frequent in a warming world, as are their acting in combination: an extended drought punctuated by a sudden downpour. Such 'whiplash' events stem from a warmer atmosphere holding more water vapour – first sucking it out of the ground, like a sponge, leaving the lands high and dry; then releasing it when full. This tendency to rising volatility in the hydrological cycle is itself non-linear, in relation to the rise in temperatures. Daniel L. Swain, Andreas F. Prein, John T. Abatzoglou et al., 'Hydroclimate Volatility on a Warming Earth', *Nature Reviews Earth and Environment* (2025) 6: 35–50.

349 See the references to self-organised criticality above.

350 David Gelles and Austyn Gaffney, '"We're in a New Era": How Climate Change Is Supercharging Disasters', *New York Times*, 10 January 2025.

351 Thereby satisfying Lukács's criteria and arguably consummating the subject-object dialectics of revolution at a higher stage, since the object here would include both society and nature – the human subject taking itself as both a social and a natural object under control.

352 Cf. Steffen et al., 'Trajectories of the Earth'; Lenton et al., 'Climate Tipping'; Armstrong McKay et al., 'Exceeding 1.5°C'; Wunderling et al., 'Global Warming'; Rosser et al., 'Polar Ice'. An implication of the domino scenario for cascading is, of course, that once the *first* domino – likely Greenland – has fallen, the rest of the sequence becomes unstoppable. Klose et al., 'What Do', 1, 8; Wunderling et al., 'Interacting Tipping', 609–10; Wunderling et al., 'Global Warming', 79.

353 Lenton et al., ‘Climate Tipping’, 595.

354 On the ethics of the recommendation, see Shue, *The Pivotal Generation*. The fact that overshoot would cause more damages than non-overshoot has been recognised in much of the literature, for example, the very early Brian C. O’Neill and Michael Oppenheimer, ‘Climate Change Impacts Are Sensitive to the Concentration Stabilization Path’, *PNAS* (2004) 101: 16411–16; Martin Parry, Jason Lowe and Clair Hanson, ‘Overshoot, Adapt and Recover’, *Nature* 458 (2009): 1103; H. Damon Matthews, Kirsten Zickfeld, Reto Knutti and Myles R. Allen, ‘Focus on Cumulative Emissions, Global Carbon Budgets and the Implications for Climate Mitigation Targets’, *Environmental Research Letters* (2018) 13: 6; Jesse F. Abrams, Chris Huntingford, Mark S. Williamson et al., ‘Committed Global Warming Risks Triggering Multiple Climate Tipping Points’, *Earth’s Future* (2023) 11: 1–11; Möller et al., ‘Achieving Net’; Masson-Delmotte et al., *Climate Change*, 617–18. The argument is forcefully made in the report by the Center for International Environmental Law and Heinrich Böll Stiftung, ‘Beyond the Limits: New IPCC Working Group II Report Highlights How Gambling on Overshoot is Pushing the Planet Past a Point of No Return’, 28 February 2022.

355 See for example, Wunderling et al., ‘Global Warming’; Abrams et al., ‘Committed Global’.

356 Some find that an overshoot would not set off most tipping points, if it is brief and moderate enough: Paul D. Ritchie, Joseph J. Clarke, Peter M. Cox and Chris Huntingford, ‘Overshooting Tipping Point Thresholds in a Changing Climate’, *Nature* (2021) 592: 517–23; Paul D. L. Ritchie, Christ Huntingford and Peter M. Cox, ‘Climate Tipping Is not Instantaneous – the Duration of an Overshoot Matters’, *Egusphere* (2024) online first; and cf. Wunderling et al., ‘Global Warming’, 79.

357 Rahmstorf, ‘Is the Atlantic?’ On 1.5°C as the upper limit, cf. Möller et al., ‘Achieving Net Zero’, 8.

358 Center for International Environmental Law and Heinrich Böll Stiftung, ‘Beyond the Limits’, 2.

359 Cf. Wunderling et al., ‘Global Warming’, 75–6.

360 Jörg Schwinger et al., ‘Emit Now’.

361 Ibid., 1657.

362 Quotation from ibid., 1656; and see further the acknowledgements of this procedure in ibid.

363 Boucher et al., ‘Reversibility in an Earth’, 1–2.

364 Wilfried Rickels and Jörg Schwinger, ‘Implications of Temperature Overshoot Dynamics for Climate and Carbon Dioxide Removal Policies in the DICE Model’, *Environmental Research Letters* (2021) 16: 5.

365 Rich descriptions of the deep evolution of the carbon cycle, its implications for our understanding of the earth – one more nail in the coffin of mechanist, non-dialectical views – and its more recently developing condition can be found in, for example, David Schwartzman, *Life, Temperature and the Earth: The Self-Organizing Biosphere* (New York: Columbia University Press, 1999); P. Falkowski, R. J. Scholes, E. Boyle et al., ‘The Global Carbon Cycle: A Test of Our Knowledge of Earth as a System’, *Science* (2000) 290: 291–6; Michael C. Jacobson, Robert J. Charlson, Henning Rodhe and Gordon H. Orians (eds), *Earth System Science: From Biogeochemical Cycles to Global Change* (London: Elsevier, 2000); David F. Baker, ‘Reassessing Carbon Sinks’, *Science* (2002) 316: 1708–9; Kririll Y. Kondratyev, Costas A. Varotsos and Vladimir F. Krapivin, *The Global Carbon Cycle and Global Climate Change* (Berlin: Springer, 2003); Taro Takahasi, ‘The Fate of Industrial Carbon Dioxide’, *Science* (2004) 305: 352–3; Christopher B. Field and Michael R. Raupach (eds), *The Global Carbon Cycle:*

Integrating Humans, Climate and the Natural World (Washington: Island Press, 2004); W. Steffen, A. Sanderson, P. D. Tyson et al., *Global Change and the Earth System: A Planet under Pressure* (Berlin: Springer, 2004); David Beerling, *The Emerald Planet: How Plants Changed Earth's History* (Oxford: Oxford University Press, 2007); Volk, *CO_2 Rising*; Pierre Friedlingstein, Michael O'Sullivan, Matthew W. Jones et al., 'Global Carbon Budget 2022', *Earth System Science Data* (2022) 14: 4811–900.

366 H. Damon Matthews, 'Can Carbon Cycle Geoengineering Be a Useful Complement to Ambitious Climate Mitigation?', *Carbon Management* (2010) 1: 135–44; Katarzyna B. Tokarska and Kirsten Zickfeld, 'The Effectiveness of Net Negative Carbon Dioxide Emissions in Reversing Anthropogenic Climate Change', *Environmental Research Letters* (2015) 10: 1–11; C. D. Jones, P. Ciais, S. J. Davis et al., 'Simulating the Earth System Response to Negative Emissions', *Environmental Research Letters* (2016) 11: 1–11; Katarzyna B. Tokarska, Kirsten Zickfeld and Joeri Rogelj, 'Path Independence of Carbon Budgets When Meeting a Stringent Global Mean Temperature Target after an Overshoot', *Earth's Future* (2019) 7: 1288; Kirsten Zickfeld, Deven Azevedo, Sabine Mathesius and H. Damon Matthews, 'Asymmetry in the Climate-Carbon Cycle Response to Positive and Negative CO_2 Emissions', *Nature Climate Change* (2021) 11: 613–17; Long Cao, Xiao-Yu Jin and Jiu Jiang, 'Simulated Carbon Cycle and Earth System Response to Atmospheric CO_2 Removal', *Advances in Climate Change Research* (2023) 14: 313–21. Cf. the analysis of the decreasing ocean carbon uptake in Jörg Schwinger and Jerry Tjiputra, 'Ocean Carbon Cycle Feedbacks under Negative Emissions', *Geophysical Research Letters* (2018) 45: 5062–70; I. Melnikova, O. Boucher, P. Cadule et al., 'Carbon Cycle Responses to Temperature Overshoot beyond 2°C: An Analysis of CMIP6 Models', *Earth's Future* (2021) 9: 1–19.

367 Long Cao and Ken Caldeira, 'Atmospheric Carbon Dioxide Removal: Long-Term Consequences and Commitment', *Environmental Research Letters* (2010) 5: 1–6; and cf. for example, Matthews, 'Can Carbon'.

368 Nicholas Gruber, Charles D. Keeling and Nicholas R. Bates, 'Interannual Variability in the North Atlantic Ocean Carbon Sink', *Science* (2002) 298: 2374–9; Fiz F. Pérez, Herlé Mercier, Marcos Vázquez-Rodríguez et al., 'Atlantic Ocean CO_2 Uptake Reduced by Weakening of the Meridional Overturning Circulation', *Nature Geoscience* (2013) 6: 146–52.

369 John E. Dore, Roger Lukas, Daniel W. Sadler and David M. Karl, 'Climate-Driven Changes to the Atmospheric CO_2 Sink in the Subtropical North Pacific Ocean', *Nature* (2003) 424: 754–7; R. A. Houghton, 'Balancing the Global Carbon Budget', *Annual Review of Earth and Planetary Science* (2007) 35: 333–4; Corinne Le Quéré, Christian Rödenbeck, Erik T. Buitenhuis et al., 'Saturation of the Southern Ocean CO_2 Sink Due to Recent Climate Change', *Science* (2007) 316: 1735–7; Archer, *The Long*, 111–12; Andrea J. Fassbender, Christopher L. Sabine and Hilary I. Palevsky, 'Nonuniform Ocean Acidification and Attenuation of the Ocean Carbon Sink', *Geophysical Research Letters* (2017) 44: 8404–13; James C. Orr, Victoria J. Fabry, Olivier Aumont et al., 'Anthropogenic Ocean Acidification over the Twenty-First Century and Its Impacts on Calcifying Organisms', *Nature* (2005) 437: 681–6; Nicolas Gruber, Dorothee C. E. Bakker, Tim DeVries et al., 'Trends and Variability in the Ocean Carbon Sink', *Nature Reviews Earth and Environment* (2023) 4: 119–34; David S. Schimel and Dustin Carroll, 'Carbon Cycle-Climate Feedbacks in the Post-Paris World', *Annual Review of Earth and Planetary Science* (2024) 52: 10, 15; Heinze, 'The Quiet Crossing', 3.

370 Stephen P. Long, Elizabeth A. Ainsworth, Andrew D. B. Leakey et al., 'Food for Thought: Lower-than-Expected Crop Yield Stimulation with Rising CO_2

Concentrations', *Science* (2006) 312: 1918–21; H. Damon Matthews, 'Implications of CO_2 Fertilization for Future Climate Change in a Coupled Climate-Carbon Model', *Global Change Biology* (2007) 13: 1068–78; M. Fernández-Martínez, J. Sardans, F. Chevallier et al., 'Global Trends in Carbon Sinks and Their Relationships with CO_2 and Temperature', *Nature Climate Change* (2018) 9: 73–9; Hao Shi, Hanqin Tian, Naiqing Pan et al., 'Saturation of Global Terrestrial Carbon Sink under a High Warming Scenario', *Global Biogeochemical Cycles* (2021) 35: 1–18; David Crisp, Han Dolman, Toste Tanhua et al., 'How Well Do We Understand the Land-Ocean-Atmosphere Carbon Cycle?', *Reviews of Geophysics* (2022) 60: 1–64. One downside to the CO_2 fertilisation effect is that plants become so full of carbon that it squeezes out protein, iron and zinc, with obvious risks for human nutrition: Matthew R. Smith and Samuel S. Myers, 'Impact of Anthropogenic CO_2 Emissions on Global Human Nutrition', *Nature Climate Change* (2018) 8: 834–9.

371 Songhan Wang, Yongguang Zhang, Weimin Ju et al., 'Recent Global Decline of CO_2 Fertilization Effects on Vegetation Photosynthesis', *Science* (2020) 370: 1295–300; Josep Penuelas, 'Decreasing Efficiency and Slowdown of the Increase in Terrestrial Carbon-Sink Activity', *One Earth* (2023) 6: 591–4.

372 Hubau et al., 'Asynchronous Carbon'.

373 Susan E. Page, Florian Siegert, John O. Rieley et al., 'The Amount of Carbon Released from Peat and Forest Fires in Indonesia during 1997', *Nature* (2002) 420: 61–5; Ph. Ciais, M. Reichstein, N. Viovy et al., 'Europe-Wide Reduction in Primary Productivity Caused by the Heat and Drought in 2003', *Nature* (2005) 437: 529–33.

374 Piyu Ke, Philippe Ciais, Stephen Sitch et al., 'Low Latency Carbon Budget Analysis Reveals a Large Decline of the Land Carbon Sink in 2023', *National Science Review* (2024) 11: 1–11 (quotation from 5).

375 Katharyn A. Duffy, Christopher R. Schwalm, Vickery L. Arcus et al., 'How Close Are We to the Temperature Tipping Point of the Terrestrial Biosphere?', *Science Advances* (2021) 7: 1–8 (quotation from 2).

376 R. J. W. Brienen, L. Caldwell, L. Duchesne et al., 'Forest Carbon Sink Neutralized by Pervasive Growth-Lifespan Trade-Offs', *Nature Communications* (2020) 11: 1–10. 'Necromass pools' is from the earlier study focusing on this effect in the Amazon: R. J. W. Brienen, O. L. Phillips, T. R. Feldpausch et al., 'Long-Term Decline of the Amazon Carbon Sink', *Nature* (2015) 344: 346.

377 Pat H. Bellamy, Peter J. Loveland, R. Ian Bradley et al., 'Carbon Losses from All Soils across England and Wales 1978–2003', *Nature* (2005) 437: 245–8; W. Knorr, I. C. Prentice, J. I. House and E. A. Holland, 'Long-Term Sensitivity of Soil Carbon Turnover to Warming', *Nature* (2005) 433: 298–301; James Heath, Edward Ayres, Malcolm Possel et al., 'Rising Atmospheric CO_2 Reduces Sequestration of Root-Derived Soil Carbon', *Science* (2005) 309: 1711–13; Eric A. Davidson and Ivan A. Janssens, 'Temperature Sensitivity of Soil Carbon Decomposition and Feedbacks to Climate Change', *Nature* (2006) 440: 275–6; Sirui Wang, Qianlai Zhuang, Outi Lähteenoja and Hinsby Cadillo-Quiroz, 'Potential Shift from a Carbon Sink to a Source in Amazonian Peatlands under a Changing Climate', *PNAS* (2018) 115: 12407–12; Ji Chen, Lars Elsgaard, Kees J. van Groenigen et al., 'Soil Carbon Loss with Warming: New Evidence from Carbon-Degrading Enzymes', *Global Change Biology* (2020) 26: 1944–52. A rare case of a report of a negative feedback mechanism from enhanced soil sink under rising temperatures is Zhengang Wang, Yizhe Zhang, Gerard Govers et al., 'Temperature Effect on Erosion-Induced Disturbances to Soil Organic Carbon Cycling', *Nature Climate Change* (2023) 13: 174–81.

378 See further Crisp et al., ‘How Well’.
379 Gruber et al., ‘Trends and Variability’, 120.
380 Weart, *The Discovery*, 108–11; Pearce, *With Speed*, 71.
381 Marten Scheffer, Victor Brovkin and Peter M. Cox, ‘Positive Feedback between Global Warming and Atmospheric CO_2 Concentration Inferred from Past Climate Change’, *Geophysical Research Letters* (2006) 33: 2. The seminal article was Peter M. Cox, Richard A. Betts, Chris D. Jones et al., ‘Acceleration of Global Warming Due to Carbon-Cycle Feedbacks in a Coupled Climate Model’, *Nature* (2000) 408: 184–7. Cf. for example, James Hansen and Makiko Sato, ‘Greenhouse Growth Rates’, *PNAS* (2004) 101: 16109–14; Pierre Friedlingstein, P. Cox, R. Betts et al., ‘Climate-Carbon Cycle Feedback Analysis: Results from the C4MIP Model Intercomparison’, *Journal of Climate* (2006) 19: 3337–53.
382 Hegel, *The Science*, 504 (emphases in original).
383 See, for example, Schimel and Carroll, ‘Carbon Cycle-Climate’; M. R. Raupach, M. Gloor, J. L. Sarmiento et al., ‘The Declining Uptake Rate of Atmospheric CO_2 by Land and Ocean Sinks’, *Biogeosciences* (2014) 11: 3453–75; and further, Christian Azar and Daniel J. A. Johansson, ‘IPCC and the Effectiveness of Carbon Sinks’, *Environmental Research Letters* (2022) 17: 1–4; Wei Cheng, Lei Huang, Zhu Liu et al., ‘Seasonal and Regional Changes in Terrestrial Carbon Uptake under an Overshoot Scenario’, *Resources, Conservation and Recycling* (2023) 195: 1–11; and cf. Charles D. Koven, Vivek K. Arora, Patricia Cadule et al., ‘Multi-Century Dynamics of the Climate and Carbon Cycle under both High and Net Negative Emissions Scenarios’, *Earth System Dynamics* (2022) 13: 885–909. But of course some models can generate the opposite result: overshoot will strengthen the sinks and so be reliable; Palter et al., ‘Climate, Ocean’, 825.
384 Christine Kaufhold, Matteo Willeit, Stefanie Talento et al., ‘Interplay between Climate and Carbon Cycle Feedbacks Could Substantially Enhance Future Warming’, *Environmental Research Letters* (2025), online first; David M. J. S. Bowman and Calum X. Cunningham, ‘Wildfires: Burning Our Way to a “Hot House Earth”?’, *Current Biology* (2025) 35: 74–6.
385 However, if the land (and by extension, the ocean) sink becomes a source *before* removal begins, outgassing can strengthen further during removal: Cao et al., ‘Simulated Carbon’, 315–16.
386 Kirsten Zickfeld, Andrew H. MacDougall and H. Damon Matthews, ‘On the Proportionality between Global Temperature Change and Cumulative CO_2 Emissions during Periods of Net Negative CO_2 Emissions’, *Environmental Research Letters* (2016) 11: 8–9; Tokarska et al., ‘Path Independence’, 1292; Zickfeld et al., ‘Asymmetry in the Climate-Carbon’, 613–14, 617; Jones et al., ‘Simulating the Earth’, 1; Gruber et al., ‘Trends and Variability’, 130; and cf. Masson-Delmotte et al., *Climate Change*, 99–100. To stay in the language of accounting, banking on removal would be like taking out a massive loan to balance the carbon budget and having to repay it at a high interest rate – only those left to honour the obligation would be other people than those indebting themselves. Shinichiro Asayama and Mike Hulme, ‘Engineering Climate Debt: Temperature Overshoot and Peak-Shaving as Risky Subprime Mortgage Lending’, *Climate Policy* (2019) 9: 937–46.
387 See, for example, Junichi Tsutsui, Yoshikatsu Yoshida, Dong-Hoon Kim et al., ‘Long-Term Climate Response to Stabilized and Overshoot Anthropogenic Forcings beyond the Twenty-First Century’, *Climate Dynamics* (2007) 28: 199–214; Soong-Ki Kim, Jongsoo Shin, Soon-Il An et al., ‘Widespread Irreversible Changes in Surface

Temperature and Precipitation in Response to CO_2 Forcing', *Nature Climate Change* (2022) 12: 834–40; Xinru Li, Kirsten Zickfeld, Sabine Mathesius et al., 'Irreversibility of Marine Climate Change Impacts under Carbon Dioxide Removal', *Geophysical Research Letters* (2020) 47: 1–11; ShiLi Yang, Di Tian, JieMing Chou et al., 'Reversibility of Historical and Future Climate Change with a Complex Earth System Model', *Theoretical and Applied Climatology* (2021) 146: 1061–68; Ali Asaadi, Jörg Schwinger, Hanna Lee et al., 'Carbon Cycle Feedbacks in an Idealized Simulation and a Scenario Simulation of Negative Emissions in CMIP6 Earth System Models', *Biogeosciences* (2024) 21: 412, 417–18, 429; Boucher et al., 'Reversibility in an Earth'; Zickfeld et al., 'On the Proportionality'; Vakilifard et al. 'Impact of Negative'; Zickfeld et al., 'Long-Term Climate', 5782, 5798, 5807; Heinze et al., 'The Quiet Crossing', 4–5.

388 Or indeed the glacier: for this and other examples of irreversible damage done to water resources by overshoot, see Adrienne Marshall, Emily Grubert and Sara Warix, 'Temperature Overshoot Would Have Lasting Impacts on Hydrology and Water Resources', *Water Resources Research* (2025) 61: 1–8.

389 On that concentration, see Kim et al., 'Widespread Irreversible'; Sadai et al., 'The Paris Agreement'; Nico Bauer, David P. Keller, Julius Garbe et al., 'Exploring Risks and Benefits of Overshooting a 1.5°C Carbon Budget over Space and Time', *Environmental Research Letters* (2023) 18: 1–18. It is, furthermore, important to remember that abstract averages are not what kill people or cause other damages: concrete impacts of climate change do. The latter have a non-linear, variable relation to the former. To take but one example: in the tropics, even a small average amount of warming might have outsized consequences simply because the temperature baseline is that much higher – an addition of heat will cross local nodal lines of tolerance. See, for example, Yi Zhang, Isaac Held and Stephan Fueglistaler, 'Projections of Tropical Heat Stress Constrained by Atmospheric Dynamics', *Nature Geoscience* (2021) 14: 133–7. A critique of the narrow focus on averages going up and (potentially) down has been developed for years: see, for example, Mike Hulme, 'Problems with Making and Governing Global Kinds of Knowledge', *Global Environmental Change* (2010) 20: 558–64; Reto Knutti, Joeri Rogelj, Jan Sedláček and Erich M. Fischer, 'A Scientific Critique of the Two-Degree Climate Change Target', *Nature Geoscience* (2015) 9: 13–18; Katharine L. Ricke, Juan B. Moreno-Cruz, Jacob Schewe et al., 'Policy Thresholds in Mitigation', *Nature Geoscience* (2016): 5–6; Esther Turnhout, Art Dewulf and Mike Hulme, 'What Does Policy-Relevant Global Environmental Knowledge Do? The Cases of Climate and Biodiversity', *Current Opinion in Environmental Sustainability* (2016) 18: 65–72.

390 On this point, cf. Malm and Carton, *Overshoot*, 77–9.

391 On the centrality of *peak* temperatures for living and policymaking in a warming (and potentially re-cooling) world, see Joeri Rogelj, Daniel Huppmann, Volker Krey et al., 'A New Scenario Logic for the Paris Agreement Long-Term Temperature Goal', *Nature* (2019) 573: 357–63; Christa Anderson, Christopher L. Weber, Christo Fabricius et al., 'Planning for Change: Conservation-Related Impacts of Climate Overshoot', *BioScience* (2020) 70: 115–18.

392 To adapt a metaphor for the swings during the glacial cycles in Alley, *The Two-Mile*, 126.

393 Jörg Schwinger, Ali Asaadi, Nadine Goris and Hanna Lee, 'Possibility for Strong Northern Hemisphere High-Latitude Cooling under Negative Emissions', *Nature Communications* (2022) 13: 1–9.

394 Peili Wu, Laura Jackson, Anne Pardaens and Nathalie Schaller, 'Extended Warming of the Northern High Latitudes Due to an Overshoot of the Atlantic Meridional Overturning Circulation', *Geophysical Research Letters* (2011) 38: 1–5.

395 See, for example, Leigh Johnson, ‘The Fearful Symmetry of Arctic Climate Change: Accumulation by Degradation’, *Environment and Planning D: Society and Space* (2010) 28: 828–47; René Marsh, ‘Billionaires Are Funding a Massive Treasure Hunt in Greenland as Ice Vanishes’, CNN, 8 August 2022; Isabeau van Halm, ‘Why the World Finds itself in a Greenland “Gold Rush”’, *Energy Monitor*, 3 July 2023; Smruthi Nadig, ‘The Nuclear Icebreakers Enabling Drilling in Russia’s Arctic’, *Mining Technology*, 8 August 2023; *Economist*, ‘How Viable is Arctic Shipping?’, 18 January 2024.

396 Reisinger and Geden, ‘Temporary Overshoot’, 1634.

397 Sharnie Kim and Adam Stephen, ‘Extreme Heat Wipes Out Almost One Third of Australia’s Spectacled Flying Fox Population’, *ABC News*, 18 December 2018; Natasha Daly, ‘Flying Foxes Are Dying En Masse in Australia’s Extreme Heat’, *National Geographic*, 11 January 2020; Matthew Mo, Mike Roache, Janine Davies et al., ‘Estimating Flying-Fox Mortality Associated with Abandonment of Pups and Extreme Heat Events during the Austral Summer of 2019–20’, *Pacific Conservation Biology* (2022) 28: 124–39.

398 For example, Aiya Zhussupova, ‘Eerie Moment Hundreds of Birds Drop Dead from the Sky after Swarming over Cities in Chilling “Sign of the Apocalypse”’, *Sun*, 16 November 2023.

399 Di Yang, Anni Yang, Jue Yang et al., ‘Unprecedented Migratory Bird Die-Off: A Citizen-Based Analysis on the Spatiotemporal Patterns of Mass Mortality Events in the Western United States’, *GeoHealth* (2021) 5: 1–13.

400 Christopher Harley in Leyland Cecco, ‘“Heat Dome” Probably Killed 1bn Animals on Canada Coast, Experts Say’, *Guardian*, 8 July 2021; see further Deepa Shivaram, ‘Heat Wave Killed an Estimated 1 Billion Sea Creatures, and Scientists Fear Even Worse’, NPR, 9 July 2021; Rachel H. White, Sam Anderson, James F. Booth et al., ‘The Unprecedented Pacific Northwest Heatwave of June 2021’, *Nature Communications* (2023) 14: 1–20.

401 For example, Jay R. Malcolm, Canran Liu, Ronald P. Neilson et al., ‘Global Warming and Extinctions of Endemic Species from Biodiversity Hotspots’, *Conservation Biology* (2006) 20: 538–48; Justin L. Penn and Curtis Deutsch, ‘Avoiding Mass Extinction from Climate Warming’, *Science* (2022) 376: 1–3; Mark C. Urban, ‘Climate Change Extinctions’, *Science* (2024) 386: 4.

402 Kevin Krajick, ‘All Downhill from Here?’, *Science* (2004) 303: 1600–2; Brittany T. Trew and Ilya M. D. Maclean, ‘Vulnerability of Global Biodiversity Hotspots to Climate Change’, *Global Ecology and Biogeography* (2021) 30: 768–83; Urban, ‘Climate Change’, 3. Although elevational gradients might also, at least for some time, give species room for habitat tracking: Trew and Maclean, ‘Vulnerability of Global’, 774, 777.

403 Céline Bellard, Camille Leclerc and Franck Courchamp, ‘Impact of Sea Level Rise on the 10 Insular Biodiversity Hotspots’, *Global Ecology and Biogeography* (2014) 23: 203–12. On the extreme risk for extinction on mountains and islands, see further Stella Manes, Mark J. Costello, Heath Beckett et al., ‘Endemism Increases Species’ Climate Change Risk in Areas of Global Biodiversity Importance’, *Biological Conservation* (2021) 257: 1–11.

404 For such factors, see, for example, Lee Hannah, Thomas E. Lovejoy and Stephen H. Schneider, ‘Biodiversity and Climate Change in Context’, in Thomas E. Lovejoy and Lee Hannah (eds), *Climate Change and Biodiversity* (New Haven: Yale University Press, 2005), 3–14; Camilla Parmesan, ‘Biotic Response: Range and Abundance Changes’, in ibid., 41–55; Brian Huntley, ‘North Temperate Responses’, in ibid., 109–25.

405 Margaret B. Davis and Ruth G. Shaw, ‘Range Shifts and Adaptive Responses to Quaternary Climate Change’, *Science* (2001) 292: 673–9.

406 Marc C. Urban, Josh J. Tewksbury and Kimberly S. Sheldon, ‘On a Collision Course: Competition and Dispersal Differences Create No-Analogue Communities and Cause Extinctions during Climate Change’, *Proceedings of the Royal Society B* (2012) 279: 2072–80; and see further, for example, Gian-Reto Walther, ‘Plants in a Warmer World’, *Perspectives in Plant Ecology, Evolution and Systematics* (2003) 6: 169–85; Gian-Reto Walther, ‘Tackling Ecological Complexity in Climate Impact Research’, *Science* (2007) 315: 606–7; K. B. Suttle, Meredith A. Thomsen and Mary E. Power, ‘Species Interactions Reverse Grassland Responses to Changing Climate’, *Science* (2007) 315: 640–2.

407 Cf. for example, David Jablonski, ‘Lessons from the Past: Evolutionary Impacts of Mass Extinctions’, *PNAS* (2001) 98: 5393–98; Cooper M. Malanoski, Alex Fansworth, Daniel J. Lunt et al., ‘Climate Change Is an Important Predictor of Extinction Risk on Macroevolutionary Timescales’, *Science* (2024) 383: 1130–4; Rothman, ‘Thresholds of Catastrophe’, 1; Scheffer, *Critical Transitions*, 178–83.

408 Gould, *The Structure*, 1296–1332. Moreover, the process of climate-induced extinction is likely to itself be highly non-linear, with nodal points constituted by, for example, clusters of thermal tolerance limits; for an important study, see Joseph Williamson, Muyan Lu, M. Florencia Camus et al., ‘Clustered Warming Tolerances and the Nonlinear Risks of Biodiversity Loss on a Warming Planet’, *Philosophical Transactions of the Royal Society B* (2025) 380: 1–16.

409 Cristian Román-Palacios and John J. Wiens, ‘Recent Responses to Climate Change Reveal the Drivers of Species Extinction and Survival’, *PNAS* (2020) 117: 4211–17.

410 Cf. Camilla Parmesan, ‘Ecological and Evolutionary Responses to Recent Climate Change’, *Annual Review of Ecology, Evolution, and Systematics* (2006) 37: 637–69; and, for example, Penn and Deutsch, ‘Avoiding Ocean’, 1; Trew and MacLean, ‘Vulnerability of Global’, 772.

411 Antonio Gazol and J. Julio Camarero, ‘Compound Climate Events Increase Tree Drought Mortality across European Forests’, *Science of the Total Environment* (2022) 816: 1–11; Florian Schnabel, Sarah Purrucker, Lara Schmitt et al., ‘Cumulative Growth and Stress Responses to the 2018–2019 Drought in a European Floodplain Forest’, *Global Change Biology* (2022) 28: 1870–83; and see further Cornelius Senf, Allan Buras, Christian S. Zang et al., ‘Excess Forest Mortality Is Consistently Linked to Drought across Europe’, *Nature Communications* (2020) 11: 1–8.

412 Andreas L. S. Meyer, Joanne Bentley, Romaric C. Odoulami et al., ‘Risks to Biodiversity from Temperature Overshoot Pathways’, *Philosophical Transactions of the Royal Society B* (2022) 377: 1–11. Cf. Anderson et al., ‘Planning for Change’. For the distinction between press and pulse and presence of both in the case of Australia, see R. M. B. Harris, L. J. Beaumont, T. R. Vance et al., ‘Biological Responses to the Press and Pulse of Climate Trends and Extreme Events’, *Nature Climate Change* (2018) 8: 579–87.

413 For a survey of those other elements, see Wang et al., ‘Mechanisms and Impacts’, 9–13, 28–33.

414 See, for example, Simon D. Donner, William J. Skirving, Christopher M. Little et al., ‘Global Assessment of Coral Bleaching and Required Rates of Adaptation under Climate Change’, *Global Change Biology* (2005) 11: 2251–65; Michael P. Lesser, ‘Coral Reef Bleaching and Global Climate Change: Can Corals Survive the Next Century?’, *PNAS* (2007) 104: 529–60; Valérie Masson-Delmotte, Panmao Zhai, Hans-Otto Pörtner et al. (eds), *Global Warming of 1.5 °C: An IPCC Special Report*

(Cambridge: Cambridge University Press, 2018), 230, 254; Armstrong McKay et al., ‘Exceeding 1.5°C’, 6–7; Wang et al., ‘Mechanisms and Impacts’, 36–8.

415 K. Frieler, M. Meinshausen, A. Golly et al., ‘Limiting Global Warming to 2°C Is Unlikely to Save Most Coral Reefs’, *Nature Climate Change* (2013) 165–70.

416 Adele M. Dixon, Piers M. Forster, Scott F. Heron et al., ‘Future Loss of Local-Scale Thermal Refugia in Coral Reef Ecosystems’, *PLOS Climate* (2022) 1: 1–20. And to this must be added the effects of acidification: Shannon G. Klein, Nathan R. Geraldi, Andrea Anton et al., ‘Projecting Coral Responses to Intensifying Marine Heatwaves under Ocean Acidification’, *Global Change Biology* (2022) 28: 1753–65.

417 Andreas L. S. Meyer and Christopher H. Trisos, ‘Ecological Impacts of Temperature Overshoot: The Journey and the Destination’, *One Earth* (2023) 6: 1615; Meyer et al., ‘Risks to Biodiversity’, 8; Penn and Deutsch, ‘Avoiding Mass’, 2.

418 Across different animal groups, the ever-underappreciated insects could be particularly sensitive: Jeffrey A. Harvey, Kévin Tougeron, Rieta Gols et al., ‘Scientists’ Warning on Climate Change and Insects’, *Ecological Monographs* (2023) 93: 1–37; and cf. R. Warren, J. Price, E. Graham et al., ‘The Projected Effects on Insects, Vertebrates, and Plants of Limiting Global Warming to 1.5°C rather than 2°C’, *Science* (2018) 360: 791–5.

419 R. Warren, J. Price, E. Graham et al., ‘Supplementary Materials for “The Projected Effects on Insects, Vertebrates, and Plants of Limiting Global Warming to 1.5°C rather than 2°C”’, *Science* (2018) 360: 6; Anderson et al., ‘Planning for Change’, 117.

420 Anderson, ‘Planning for Change’, 117.

421 Cf. for example, Reisinger and Geden, ‘Temporary Overshoot’, 1631–3; Willcock et al., ‘Earlier Collapse’, 1336; Wunderling et al., ‘Global Warming’, 79, 81.

422 Lenton et al., ‘Climate Tipping’, 592. Needless to point out, the melting of the West Antarctic Ice Sheet is only one source of sea level rise.

8. Browse Our New Catalogue

1 See for example, Fiekowsky, *Climate Restoration*, 115–16. But the resistance to languages of magic is not universal among the advocates: see below.
2 Simon L. Lewis and Mark A. Maslin, 'Defining the Anthropocene', *Nature* (2015) 519: 174.
3 Alexander Koch, Chris Bierley, Mark M. Maslin and Simon L. Lewis, 'Earth System Impacts of the European Arrival and Great Dying in the Americas after 1492', *Quaternary Science Reviews* (2019) 207: 13–36.
4 The dying and the ice age: ibid.
5 Freeman J. Dyson, 'Can We Control the Carbon Dioxide in the Atmopshere?', *Energy* (1977) 2: 289. For more on this article, see Malm and Carton, *Overshoot*, 81–2. On the history of this idea, see also Larry Lohmann, 'The Dyson Effect: Carbon "Offset" Forestry and the Privatisation of the Atmosphere', *International Journal of Environment and Pollution* (2001) 15: 51–78. Dyson was not in fact the first to propose the idea of using trees to compensate for continued emissions. That honour goes to William Nordhaus, in a similarly titled paper published two years earlier: William D. Nordhaus, 'Can We Control Carbon Dioxide?', International Institute of Applied Systems Analysis, Austria, 1975, Working Paper, 1975, 8.
6 William Booth, 'Johnny Appleseed and the Greenhouse', *Science* (1988) 242: 19–20.
7 Daniel Lashof quoted in ibid.
8 Ibid. The plan for an Australia of sycamores was laid out in Gregg Marland, 'The Prospect of Solving the CO_2 Problem Through Global Reforestation', United States Department of Energy, February 1988.
9 *USA Today*, 'Trump Plants WH Maple Tree; Reopens National Parks', 22 April 2020; Mary B. Neumayr, 'President Trump Signs One Trillion Trees Executive Order, Promoting Conservation and Regeneration of Our Nation's Forests', The White House, 16 October 2020. Cf. Lisa Friedman, 'A Trillion Trees: How One Idea Triumphed Over Trump's Climate Denialism', *New York Times*, 12 February 2020.
10 Neumayr, 'President Trump'.
11 Greta Thunberg, Margaret Atwood, Michael Mann et al., 'A Natural Solution to the Climate Disaster', *Guardian*, 3 April 2019.
12 'Greta Thunberg and George Monbiot Make Short Film on the Climate Crisis', YouTube, 19 September 2019. Monbiot boasted that the film was watched more than 60 million times: 'About George', George Monbiot, 2024.
13 George Monbiot, 'The Natural World Can Help Save Us from Climate Catastrophe', *Guardian*, 3 April 2019.
14 Bronson W. Griscom, Justin Adams, Peter W. Ellis et al., 'Natural Climate Solutions', *PNAS* (2017) 114: 11645–50. For later overviews, see Ignacio Palomo, Bruno Locatelli, Iago Otero et al., 'Assessing Nature-Based Solutions for Transformative Change', *One Earth* (2021), 4: 730–41; B. Buma, D. R. Gordon, K. M. Kleisner et al., 'Expert Review of the Science Underlying Nature-Based Climate Solutions', *Nature Climate Change* (2024) 14: 402–6. For the career of the concept, see Rob Bellamy and Shannon Osaka, 'Unnatural Climate Solutions?', *Nature Climate Change* (2020) 10: 98–9; Nathalie Seddon, Alison Smith, Pete Smith et al., 'Getting the Message Right on Nature-Based Solutions to Climate Change', *Global Change Biology* (2021) 27: 1518–46; and for its intellectual history and market value, see Shannon Osaka, Rob Bellamy and Noel

Castree, ‘Framing “Nature-Based” Solutions to Climate Change’, *WIREs Climate Change* (2021) 12: 1–20. The latter article argues that the jargon around natural climate solutions validates a constructionist and/or hybridist conception of nature. But every critique of natural climate solutions – including that offered by said authors as well as everything said in the present book – rather presupposes a realist conception of nature and an analytical distinction between the natural and the social. See, for example, Kate Soper, *What Is Nature? Culture, Politics and the Non-Human* (Oxford: Wiley-Blackwell, 1995); Andreas Malm, *The Progress of this Storm: Nature and Society in a Warming World* (London: Verso, 2018).

15 Susan C. Cook-Patton, C. Ronnie Drever, Bronson W. Griscom et al., ‘Protect, Manage and then Restore Lands for Climate Mitigation’, *Nature Climate Change* (2021) 11: 1027–34; and cf. for example, Bronson W. Griscom, Jonah Busch, Susan C. Cook-Patton et al., ‘National Mitigation Potential from Natural Climate Solutions in the Tropics’, *Philosophical Transactions of the Royal Society B* (2020) 375: 2; Cécile A. J. Girardin, Stuart Jenkins, Nathalie Seddon et al., ‘Nature-Based Solutions Can Help Cool the Planet – If We Act Now’, *Nature* (2021) 593: 192.

16 Viola H. A. Heinrich, Ricardo Dalagnol, Henrique L. G. Cassol et al., ‘Large Carbon Sink Potential of Secondary Forests in the Brazilian Amazon to Mitigate Climate Change’, *Nature Communication* (2021) 12: 1–11. For the general pattern, see Molly Hawes, ‘Planting Carbon Storage’, *Nature Climate Change* (2018) 8: 556–8; Blanca Bernal, Lara T. Murray and Timothy R. H. Pearson, ‘Global Carbon Dioxide Removal Rates from Forest Landscape Restoration Activities’, *Carbon Balance Management* (2018) 13: 1–13.

17 Cf. Lovejoy and Nobre, ‘Amazon Tipping Point: Last’, 1; Xu et al., ‘Deforestation Triggering’, 8; Amigo, ‘The Amazon’s Fragile’, 507.

18 Jonah Busch, Jens Engelmann, Susan C. Cook-Patton et al., ‘Potential for Low-Cost Carbon Dioxide Removal through Tropical Reforestation’, *Nature Climate Change* (2019) 9: 463–6; Griscom et al., ‘National Mitigation’.

19 Francesco S. R. Pausata, Marco Gaetani, Gabriele Messori et al., ‘The Greening of the Sahara: Past Changes and Future Implications’, *One Earth* (2020) 2: 244. A project on the border between reforestation and afforestation in this region is the ‘Great Green Wall’ of the Sahel, with a touted potential for considerable carbon sequestration: see, for example, A. Mirzabaev, M. Sacande, F. Motlagh et al., ‘Economic Efficiency and Targeting of the African Great Green Wall’, *Nature Sustainability* (2022) 5: 17–25.

20 Upksha Caldera and Christian Breyer, ‘Afforesting Arid Land with Renewable Electricity and Desalination to Mitigate Climate Change’, *Nature Sustainability* (2023) 6: 526–38.

21 David Birge, Sneha Mandham, Waishan Qiu and Alan M. Berger, ‘Potential for Sustainable Use of Trees in Hot Arid Regions: A Case Study of Emirati Neighbourhoods in Abu Dhabi’, *Landscape and Urban Planning* (2019) 190: 1–16. It was this study that inspired Caldera and Breyer, ‘Afforesting Arid’.

22 Yishan Wong, ‘Scaling Reforestation with Solar-Powered Deforestation’, Terraformation, 16 November 2020; Terraformation, ‘Update from Pacific Flight at Kaupaloa’, 3 November 2021. The ex-CEO of Reddit: Wong. The area in question had been covered by sandalwood before colonisation.

23 Cynthia Sweeney, ‘This Big Island Startup Turns Degraded Land into Thriving Ecosystems’, *Hawaii Business Magazine*, 18 January 2023.

24 This was emphasised already in Booth, ‘Johnny Appleseed’, 19.

25 Jonathan Guthrie, ‘There’s a Tree for Everyone in this World’, *Financial Times*, 19 November 2021.

26 Akira S. Mori, Laura E. Dee, Andrew Gonzalez et al., ‘Biodiversity-Productivity Relationships Are Key to Nature-Based Climate Solutions’, *Nature Climate Change* (2021) 11: 543–50; and see further, for example, Griscom et al., ‘Natural Climate’, 11648; Girardin et al., ‘Nature-Based Solutions’; Cook-Patton et al., ‘Protect, Manage’, 1029, 1031.

27 On mangrove restoration as a natural climate solution, see, for example, Peter I. Macreadie, Micheli D. P. Costa, Trisha B. Atwood et al., ‘Blue Carbon as a Natural Climate Solution’, *Nature Reviews Earth and Environment* (2021) 2: 826–39; on protecting against storms, Pelayo Menéndez, Iñigo J. Losada, Saul Torres-Ortega et al., ‘The Global Flood Protection Benefits of Mangroves’, *Scientific Reports* (2020) 10: 1–11; Stijn Temmerman, Erik M. Horstman, Ken W. Krauss et al., ‘Marshes and Mangroves as Nature-Based Coastal Storm Buffers’, *Annual Review of Marine Science* (2023) 15: 95–118; Dale, *Climate Change*, 62–6; and cf. for example, Seddon et al., ‘Getting the Message’, 1527; Smith, *Pandora’s Toolbox*, 119. For some general reflections on the synergies between adaptation and removal, see Holly J. Buck, Jay Fuhrman, David R. Morrow et al., ‘Adaptation and Carbon Removal’, *One Earth* (2020) 3: 425–35.

28 Joris P. G. M. Cromsigt, Mariska te Beest, Graham I. H. Kerley et al., ‘Trophic Rewilding as a Climate Change Mitigation Strategy?’, *Philosophical Transactions of the Royal Society B* (2018): 7; Oswald J. Schmitz, Magnus Sylvén, Trisha B. Atwood et al., ‘Trophic Rewilding Can Expand Natural Climate Solutions’, *Nature Climate Change* (2023) 13: 325. The example was also adduced in Oswald J. Schmitz, ‘How “Natural Geoengineering” Can Help Slow Global Warming’, *Yale Environment 360*, 25 January 2016. Here it was claimed that the recovering wildebeest had turned the Serengeti into a ‘sink so large that it is estimated to offset all of East Africa’s current annual fossil fuel carbon emissions’. If this was true, perhaps it said more about the size of fossil fuel combustion in East Africa than about the potentials of rewilding.

29 Oswald J. Schmitz and Magnus Sylvén, ‘Animating the Carbon Cycle: How Wildlife Conservation Can Be a Key to Mitigate Climate Change’, *Environment: Science and Policy for Sustainable Development* (2023) 65: 9; Schmitz et al., ‘Trophic Rewilding’, 326.

30 Schmitz and Sylvén, ‘Animating the Carbon’, 9; Cromsigt et al., ‘Trophic Rewilding’, 9.

31 Other terrestrial sinks than forests were crucial to this project, notably grasslands and soil. For these two, see Yongfei Bai and M. Francesca Cotrufo, ‘Grassland Soil Carbon Sequestration: Current Understanding, Challenges, and Solutions’, *Science* (2022) 377: 1–6; D. A. Bossio, S. C. Cook-Patton, P. W. Ellis et al., ‘The Role of Soil Carbon in Natural Climate Solutions’, *Nature Sustainability* (2020) 3: 391–8.

32 For this history, see Keith Hart and Vishnu Padayachee, ‘A History of South African Capitalism in National and Global Perspective’, *Transformation: Critical Perspectives on Southern Africa* (2013) 81/82: 55–85; for the coal, Anglo-American, ‘Steelmaking Coal’, 2024; for Oppenheimer, for example, Stephanie Churchill, ‘Jonathan Oppenheimer Wins Tax Residence Dispute with HMRC’, Churchill Taxation, 5 May 2022.

33 Rewild Capital, ‘Tsuwalu Kalahari Carbon Project’, 2024; Yves Vanderhaeghen, ‘Carbon Revenue Can Boost Wildlife Economies and Restore Ecosystems’, Oppenheimer Generations Research and Conservation, 7 December 2023.

34 Eleanor Salter, ‘Rewilding, or Just a Greenwashed Land Grab? It All Depends on Who Benefits’, *Guardian*, 28 May 2022; Natasha White, ‘One Investor’s Uphill Battle to Turn Rewilding into a Multi-Billion Dollar Industry’, *Bloomberg*, 28 September 2023; Vicky Allan, ‘Rewild Scotland: “Beavers in All Rivers. Lynx and Wolf Back”’, *The*

Herald, 21 May 2021; Vicky Allan, ‘Rewilding Estates of Scotland: Trees, Carbon, Who Owns Them’, *The Herald*, 20 November 2023.

35 Marc Macias-Fauria, Paul Jepson, Nikita Zimov and Yadvinder Malhi, ‘Pleistocene Arctic Megafaunal Engineering as a Natural Climate Solution?’, *Philosophical Transactions of the Royal Society B* (2019) 375: 1–13; and cf. the earlier Sergey A. Zimov, ‘Pleistocene Park: Return of the Mammoth’s Ecosystem’, *Science* (2005) 308: 796–8. Also, Schmitz and Sylvén, ‘Animating the Carbon’, 7–8.

36 Liberty Science Center, ‘George Church’, 2024.

37 George Church, ‘Please Reanimate’, *Science* (2013) 309: 12; and see further Leslie Paul Thiele, ‘Nature 4.0: Assisted Evolution, De-Extinction, and Ecological Restoration Technologies’, *Global Environmental Politics* (2020) 3: 17–18, 22.

38 Xiaohan Yang, Degao Liu, Haiwei Lu et al., ‘Biological Parts for Plant Biodesign to Enhance Land-Based Carbon Dioxide Removal’, *BioDesign Research* (2021): 1.

39 Ibid., 3. Cf. Maitri Verma and Alok Kumar Verma, ‘Effect of Plantation of Genetically Modified Trees on the Control of Atmospheric Carbon Dioxide: A Modeling Study’, *Natural Resource Modeling* (2021) 34: 1–24.

40 Yusmin Tao, Li-Wei Chiu, Jacob W. Hoyle et al., ‘Enhanced Photosynthetic Efficiency for Increased Carbon Assimilation and Woody Biomass Production in Engineered Hybrid Poplar’, *Forests* (2023) 14: 1–21.

41 Living Carbon, ‘Our Work: Carbon Projects’, 2022.

42 For the achivements of Living Carbon in these years, see further Sara Donchey and Molly McCrea, ‘Biotech Startup Living Carbon Enhances Trees’ Ability to Capture Climate-Warming CO_2’, *CBS News*, 31 August 2023; and in particular Boyce Upholt, ‘Inside the Quest to Engineer Climate-Saving “Super Trees”’, *MIT Technology Review*, 8 June 2023.

43 The Salk Institute, ‘Harnessing Plants Initiative: Overview’, 2023.

44 Adam Popescu, ‘This Scientist Thinks She Has the Key to Curb Climate Change: Super Plants’, *Guardian*, 17 April 2019.

45 Innovative Genomics Institute, ‘Supercharging Plants and Soils to Remove Carbon from the Atmosphere’, 2022.

46 Max Schubert, Tzu-Chieh Tang, Isabella Goodchild-Michelman et al., ‘Cyanobacteria Newly Isolated from Marine Volcanic Seeps Display Rapid Sinking and Robust, High-Density Growth’, *Applied Environmental Microbiology* (2024) 90: 1–23.

47 Sachi Kitajima Mulkey, ‘Scientists Found a New Ally in the Fight to Clean Up CO_2 Emissions: “Chonkus”’, *Grist*, 5 November 2024.

48 Yuman Tao in Donchey and McCrea, ‘Biotech Startup’.

49 Nils Markusson, ‘Natural Carbon Removal as Technology’, *WIREs Climate Change* (2022) 13: 1–6.

50 K. Möllersten and J. Yan, ‘Economic Evaluation of Biomass-Based Energy Systems with CO_2 Capture and Sequestration in Kraft Pulp Mills: The Influence of the Price of CO_2 Emission Quota’, *World Resource Review* (2001) 13: 509–25.

51 Leo Hickman, ‘Timeline: How BECCS Became Climate Change’s “Saviour” Technology’, *Carbon Brief*, 13 April 2016. The hub: Institute for Applied Systems Analysis.

52 M. Obersteiner, Ch. Azar, P. Kauppi et al., ‘Managing Climate Risk’, *Science* (2001) 294: 786.

53 Ibid.

54 See Malm and Carton, *Overshoot*, 63–72.

55 Christopher Consoli, ‘2019 Perspective: Bioenergy and Carbon Capture and Storage’, *Global CCS Institute*, 2019, 5. Not even this plant regularly captured more than 10–12 per cent of all its emissions: see Brendan Gibbons, ‘In Illinois, a Massive Taxpayer-Funded Carbon Capture Project Fails to Capture about 90 Percent of Plant’s Emissions’, *Oil and Gas Watch*, 25 April 2024. For more on the implications and context of this plant, see further Malm and Carton, *Overshoot*, 79–80. There were also four small pilot plants, to which we shall return.

56 Stockholm Exergi, ‘Stockholm – här suger vi bort koldioxid ur atmosfären’, n.d.

57 Beccs Stockholm, ‘Carbon Dioxide Removal: How It Works’, n.d.; Stockholm Exergi, ‘BECCS – Negative Emissions’, n.d.

58 Beccs Stockholm, ‘Stockhom Exergi’s BECCS Project Receives 180 Million EUR in EU Funding’, 1 April 2022.

59 Angeli Mehta, ‘Burning Questions Surround Biomass-Based Carbon Removals’, *Reuters*, 23 October 2023; and see below.

60 See for example, *Resumé*, ‘Alla ska veta att Stockholm Exergi suger’, 29 May 2023. On the politics of BECCS in Sweden, see further Ashley Almqvist-Ingersoll, ‘Risking Delay: The Storylines of (Bioenergy with) Carbon Capture and Storage in Swedish Parliamentary Discourse’, *Frontiers in Climate* (2025) 6: 1–12.

61 Hanna Ziady, ‘How the Dirtiest Power Station in Western Europe Switched to Renewable Energy’, *CNN*, 23 October 2019.

62 But Drax remained the largest point-source of emissions in the UK; the combustion of biomass does, of course, still produce CO_2. See for example, David Vetter, ‘U.K. Bets on “$40 Billion” Carbon Capture Tech, But Critics Say It’s Hot Air’, *Forbes*, 19 January 2024.

63 Drax, ‘Drax to Launch New Business Focused on Becoming the Global Leader in Large-Scale Carbon Removals’, 25 January 2024.

64 Laura Paddison, ‘UK Government Approves Controversial $2.5B Project for “Carbon Negative” Power Plant’, *CNN*, 17 January 2024; Vetter, ‘U.K. Bets’.

65 Mehta, ‘Burning Questions’.

66 Phoebe Cooke, ‘Drax Eyeing California as Site of New Biomass Carbon Capture Plant’, *DeSmog*, 28 June 2022. And it happened in Denmark, where the government doled out millions to energy company Ørsted to stick CCS onto two of its existing woodchip and straw-fired power plants. Ørsted expected the first removals to happen in 2026. Ørsted, ‘Ørsted Begins Construction of Denmark’s First Carbon Capture Project’, 4 December 2023.

67 Dimana Doneva, ‘Red Trail Energy Launches Carbon Capture Site in North Dakota’, *Carbon Herald*, 15 August 2022; Violet George, ‘Red Trail Energy Becomes First Ethanol Plant to Generate Carbon Credits’, *Carbon Herald*, 6 March 2024. On the category of durable removals, see below.

68 For details, see Jin Sun Cha, Sung Hoon Park, Sang-Chul Jung et al., ‘Production and Utilization of Biochar: A Review’, *Journal of Industrial and Engineering Chemistry* (2016) 40: 1–15; Jianlong Wang and Shizong Wang, ‘Preparation, Modification and Environmental Application of Biochar: A Review’, *Journal of Cleaner Production* (2019) 227: 1002–22; Alexis Neukirch, Deborah S. Page-Dumroese, Nate Anderson et al. ‘Biochar Basics: An A-to-Z Guide to Biochar Production, Use, and Benefits’, US Department of Agriculture, Science You Can Use Bulletin, 2022. Upbeat estimates of total sequestration capacity for biochar hovers around three gigatonnes per year: Candelaria Bergero, Marshall Wise, Patrick Lamers et al., ‘Biochar as a Carbon Dioxide Removal Strategy in Integrated Long-Run Mitigation Scenarios’, *Environmental Research Letters* (2024) 19: 1–13.

69 Bruno Glaser and Jago Jonathan Birk, ‘State of the Scientific Knowledge on Properties and Genesis of Anthropogenic Dark Earths in Central Amazonia (*Terra Preta de Índio*)’, *Geochimica et Cosmochimica Acta* (2012) 82: 39–51; Joana Bezerra, Esther Turnhout, Isabel Melo Vasquez et al., ‘The Promises of the Amazonian Soil: Shifts in Discourses of Terra Preta and Biochar’, *Journal of Environmental Policy and Planning* (2019) 21: 623–35; Wenfu Chen, Jun Meng, Xiaori Han et al., ‘Past, Present, and Future of Biochar’ *Biochar* (2019) 1: 75–87.

70 For the many win–win benefits, see David Chiaramonti, Johannes Lehmann, Franco Berruti et al., ‘Biochar Is a Long-Lived Form of Carbon Removal, Making Evidence-Based CDR Projects Possible’, *Biochar* (2024) 6: 1–6.

71 S. M. Smith, O. Geden, G. F. Nemet et al., *The State of Carbon Dioxide Removal*, University of Oxford, Smith School of Enterprise and the Environment, 2023, 21, 25. For just one study from the days of Paris, see Pete Smith, ‘Soil Carbon Sequestration and Biochar as Negative Emission Technologies’, *Global Change Biology* (2016) 22: 1315–24.

72 ‘About Puro.Earth’, Puro Earth, 2023. On the aspirations of this company, see, for example, Leigh Collins, ‘World’s First Carbon-Removal Marketplace Offers Businesses an Easy Route to Net-Zero Emissions’, *Recharge*, 30 June 2020.

73 ‘Puro Qualified Listing: American BioCarbon’, Puro Earth, 2023.

74 Smith, ‘Soil Carbon’, 7–8.

75 Terrafirm, ‘Our Research: Carbon Sequestration through Wood Burial’, 2023.

76 Ning Zeng, ‘Carbon Sequestration via Wood Burial’, *Carbon Balance and Management* (2008) 3: 1.

77 Ning Zeng and Henry Hausmann, ‘Wood Vault: Remove Atmospheric CO_2 with Trees, Store Wood for Carbon Sequestration for Now and as Biomass, Bioenergy and Carbon Reserve for the Future’, *Carbon Balance and Management* (2022) 17: 1–29.

78 James Temple, ‘A Stealth Effort to Bury Wood for Carbon Removal Has Just Raised Millions’, *MIT Technology Review*, 15 December 2022; and cf. Catherine Early, ‘Analysis: Why Biomass Removals Credits like Biochar Are Luring Investors’, *Reuters*, 15 November 2023.

79 ‘Delaying Wood Decomposition’, Carbon Containment Lab, 2024.

80 James Temple, ‘Inside Charm Industrial’s Big Bet on Corn Stalks for Carbon Removal’, *MIT Technology Review*, 26 May 2022.

81 Emily Pontecorvo, ‘Meet the Startup Producing Oil to Fight Climate Change’, *Grist*, 18 May 2021.

82 ‘Frontier Buyers Sign First $53M in Offtake Agreements with Charm Industrial’, Frontier, 2023; ‘JPMorgan Chase Seeks to Scale Investment in Emerging Carbon Removal Technologies, Announces Agreements Intended to Durably Remove and Store 800,000 Tons of Carbon’, JPMorgan Chase, 27 May 2023.

83 Maria Gallucci, ‘Inside Charm Industrial’s Multimillion-Dollar Bid to Remove CO_2 with Plants’, *Canary Media*, 19 June 2023.

84 Shaun Meehan in Pontecorvo, ‘Meet the Startup’.

85 Peter Reinhardt, ‘Accelerating Carbon Removal with Our $100m Series B’, Charm Industrial, 2023.

86 ‘Proven Technology Unlocks a Simple Carbon Removal Process’, Vaulted Deep, 2024.

87 Emily Pontecorvo, ‘Does Carbon Removal Need to Be Dumb To Work?’, *Heatmap*, 1 May 2024.

88 ‘An Advance Market Commitment to Accelerate Carbon Removal’, Frontier, 2023.

89 Pontecorvo, ‘Does Carbon’.

90 Kari De Pryck and Miranda Boettcher, ‘The Rise, Fall and Rebirth of Ocean Carbon Sequestration as a Climate “Solution”’, *Global Environmental Change* (2024) 85: 6.

91 Elizabeth McLeod, Gail L. Chmura, Steven Bouillon et al., ‘A Blueprint for Blue Carbon: Toward an Improved Understanding of the Role of Vegetated Coastal Habitats in Sequestering CO_2’, *Frontiers in Ecology and Environment* (2011) 9: 552–60; Macreadie et al., ‘Blue Carbon’; De Pryck and Boettcher, ‘The Rise, Fall’, 6–7.

92 M. Troell, P. J. G. Henriksson, A. H. Buschmann et al., ‘Farming the Ocean: Seaweeds as a Quick Fix for the Climate?’, *Reviews in Fisheries Science and Aquaculture* (2023) 31: 285–95; Rod Fujita, Simona Augyte, Jennifer Bender et al., ‘Seaweed Blue Carbon: Ready? Or Not?’ *Marine Policy* (2023) 155: 1–15; Sander W. K. van den Burg, Sophie J. I. Koch, Marnix Poelman, Jeroen Veraart et al., ‘Seaweed as Climate Mitigation Solution: Categorizing and Reflecting on Four Climate Mitigation Pathways’, *WIREs Climate Change* (2023), online first; Benjamin K. Sovacool, Chad M. Baum, Sean Low and Livia Fritz, ‘The Sociotechnical Dynamics of Blue Carbon Management: Testing Typologies of Ideographs, Innovation, and Co-Impacts for Marine Carbon Removal’, *Environmental Science and Policy* (2044) 155: 17–20.

93 Jordan Breighner, Max Chalfin, Rishi Masalia et al., ‘White Paper: Sustainably Amplifying the Natural Carbon Cycle’, Running Tide, 2023; for blue carbon as natural climate solution, see Macreadie et al., ‘Blue Carbon’.

94 ‘Running Tide’, Lower Carbon Capital, 2024; ‘World Leader in Ocean Carbon Removal’, Running Tide, 2024.

95 This draws on research by Nicholas LePage. Cf. ‘Removing Carbon; Restoring Ocean Health; Fixing the Planet’, Running Tide, 2023; James Temple, ‘Running Tide Is Facing Scientist Departures and Growing Concerns over Seaweed Sinking for Carbon Removal’, *MIT Technology Review*, 16 June 2022; Jesse Klein, ‘Shopify, Startup Running Tide Tout Ocean Carbon Removal Breakthrough’, *Green Biz*, 9 August 2023. Seeding the buoys with algae was the original idea, but the company soon took a more promiscuous approach to ocean removal. Its first (and last, as it would turn out) act of removal featured no algae but small wooden buoys coated in minerals. Using terrestrial biomass and sinking it to the bottom of the sea was always part of the business model, the company argued. See Bjartmar Oddur Þeyr Alexandersson and Sunna Ósk Logadóttir, ‘Sökktu Kurli Og Seldu Syndaaflausn [Sink a Hole and Sell Absolution]’, *Heimildin*, 14 June 2024; interview with Running Tide, 16 April 2024.

96 Chan Zuckerberg Initiative, ‘Chan Zuckerberg Initiative Invests in Promising Climate Change Solutions’, 2022; Running Tide, ‘Running Tide Becomes Microsoft’s First Open Ocean-Based Carbon Removal Supplier’, 29 March 2023; Dimana Doneva, ‘Running Tide Goes International, Elicits Both Hope and Criticism’, *Carbon Herald*, 13 August 2022; Temple, ‘Running Tide’.

97 Quoted in Temple, ‘Running Tide’.

98 Running Tide, ‘Removing Carbon’. Running Tide had a competitor in Seafields, whose plan it was to establish a floating field of the weed sargassum, make it as large as Croatia and consign it to the gyres of the south Atlantic. Some kind of machines would harvest the crop in bales. David Reith and Justin Rowlatt, ‘Climate Change: Can an Enormous Seaweed Farm Help Curb It?’, BBC, 16 October 2022.

99 James Temple, ‘Companies Hoping to Grow Carbon-Sucking Kelp May Be Rushing Ahead of the Science’, *MIT Technology Review*, 19 September 2021; and see further ‘The Science and Technology behind Seaweed Sinking’, Pull to Refresh, 2023.

100 For example, the Norwegian SINTEF, ‘Capturing Carbon with Sugar Kelp’, 2022; see also ‘What We Do’, Carbon Kapture, 2023; cf. De Pryck and Boettcher, ‘The Rise, Fall’, 2.

101 Rewind, 2024.

102 Alison F. Takemura, ‘Can We Fight Climate Change by Sinking Carbon into the Sea?’, *Canary Media*, 11 May 2023; Julia Jacob, ‘Researchers Find New Way to Store Carbon Dioxide Absorbed by Plants at the Bottom of the Black Sea’, *ABC News*, 19 September 2023; James Jackson, ‘A Look Inside the Plan to Store Carbon at the Bottom of the Black Sea’, *Grist*, 12 September 2023; Saima Sidik, ‘Plant Waste Buried at Sea to Fight Climate Change’, *Science* (2024) 383: 11 (words quoted from Sidik). The man and CEO: Ram Amar. A Houston-based company called Carboniferous planned to sink sugarcane waste in oxygen-starved parts of the Gulf of Mexico. Sidik, ‘Plant Waste’, 11.

103 Eyal Harel in Takemura, ‘Can We’.

104 BlueGreen Water Technologies, ‘BlueGreen’s Net Blue’, 2023.

105 Bahram Barati, Kuo Zeng, Jan Baeyens et al., ‘Recent Progress in Genetically Modified Microalgae for Enhanced Carbon Dioxide Sequestration’, *Biomass and Bioenergy* (2021) 145: 1; cf. Mohamed Ali Zahed, Elaheh Movahed, Arezoo Khodayari et al., ‘Biotechnology for Carbon Capture and Fixation: Critical Review and Future Directions’, *Journal of Environmental Management* (2021) 293: 1–14; A. Saravanan, V. C. Deivayani, P. Senthil Kumar et al., ‘CO_2 Bio-Mitigation Using Genetically Modified Algae and Biofuel Production towards a Carbon Net-Zero Society’, *Bioresource Technology* (2022) 363: 1–12.

106 ‘Our Process’, Brilliant Planet, 2023; Violet George, ‘Top 10 Carbon Removal Companies in 2023’, *Carbon Herald*, 26 June 2023.

107 ‘To Restore Our Climate, Billions of Tons of CO_2, Mostly from Fossil Fuel Use, Must Be Removed Annually. It’s Impossible without Oceans’, Ocean-Based Climate Solutions, 2023.

108 James E. Lovelock and Chris G. Rapley, ‘Ocean Pipes Could Help the Earth to Cure Itself’, *Nature* (2007) 449: 403. For the intellectual and political context, see the brilliant Leah Aronowsky, ‘Gas Guzzling Gaia, or: A Prehistory of Climate Change Denialism’, *Critical Inquiry* (2021) 47: 306–27.

109 For a detailed description of this technology – and many more from in the ocean CDR space – see, for example, the National Academies of Sciences, Engineering, and Medicine, *A Research Strategy for Ocean-Based Carbon Dioxide Removal and Sequestration* (Washington, DC: The National Academies Press, 2022); Antonius Gagern, Justin Manley and Lydia Kapsenberg, ‘Ocean-Based Carbon Dioxide Removal: A New Frontier in the Blue Economy’, *Marine Technology Society Journal* (2022) 56: 40–48.

110 Heidi C. Pearson, Matthew S. Savoca, Daniel P. Costa et al., ‘Whales in the Carbon Cycle: Can Recovery Remove Carbon Dioxide?’, *Trends in Ecology and Evolution* (2023) 38: 238–49. Cf. Trish J. Lavery, Ben Roudnew, Peter Gill et al., ‘Iron Defecation by Sperm Whales Stimulates Carbon Export in the Southern Ocean’, *Proceedings of the Royal Society B* (2010) 277: 3527–31. Whale carcasses as carbon sinks are the focus of Anaëlle Durfort, Gaël Mariani, Vivitskaia Tulloch et al., ‘Recovery of Carbon Benefits by Overharvested Baleen Whale Populations Is Threatened by Climate Change’, *Proceedings of the Royal Society B* (2022) 289: 1–8. For one example of the media hype, see Rachel Ramirez, ‘Whales Can Have an Important but Overlooked Role in Tackling the Climate Crisis, Researchers Say’, *CNN*, 15 December 2022.

111 The Whale Carbon Plus Project, ‘Developing Climate Change and Nature-Positive Solutions by Protecting Whales’, 2023; Andrew Chapman, ‘Can Putting a Price on a Whale Save the Environment?’, *Scientific American*, April 2023.

112 Ralph Chami, Tomas Cosimano, Connel Fullenkamp and Sena Oztosun, ‘Nature’s Solution to Climate Change’, IMF, December 2019. This intervention by the IMF is the

point of departure for the excellent study by Adrienne Buller, *The Value of a Whale: On the Illusions of Green Capitalism* (Manchester: Manchester University Press, 2022), 1.

113 Todd Woody, 'Scientists to Carbon Markets: Don't Monetize the Whales', *Bloomberg*, 15 December, 2022.

114 Sallie W. Chisholm, 'Stirring Times in the Southern Ocean', *Nature* (2000) 407: 685–87.

115 T. John Hart, *On the Phytoplankton of the Southwest Atlantic and the Bellingshausen Sea, 1929–1931* (Cambridge: Cambridge University Press, 1934).

116 Victor Smetacek and S. W. A. Naqvi, 'The Next Generation of Iron Fertilization Experiments in the Southern Ocean', *Philosophical Transactions of the Royal Society A* (2008) 366: 3947–67. The story is also told in Fiekowsky, *Climate Restoration*, 118–27.

117 John H. Martin and Steve E. Fitzwater, 'Iron Deficiency Limits Phytopankton Growth in the North-East Pacific Subarctic', *Nature* (1988) 331: 341–43; John H. Martin, 'Glacial-Interglacial CO_2 Change: The Iron Hypothesis', *Paleoceanography* (1990) 5: 1–13; John H. Martin, R. Michael Gordon and E. F. Steve, 'Iron in Antarctic Waters', *Nature* (1990) 345: 156–58. For a more recent confirmation of this feedback mechanism, see Alfredo Martínez-García, Daniel M. Sigman, Haojia Ren et al., 'Iron Fertilization of the Subantarctic Ocean During the Last Ice Age', *Science* (2014) 343: 1347–50.

118 John H. Martin, 'Iron, Liebig's Law, and the Greenhouse', *Oceaonography* (1991) 4: 54.

119 Ibid.; and cf. Anthony G. Davies, 'Taking a Cool Look at Iron', *Nature* (1990) 345: 114–15.

120 Martin et al., 'Iron in Antarctic', 156; and see also Martin, 'Iron, Liebig's'.

121 William Booth, 'Ironing out "Greenhouse Effect"', *Washington Post*, 20 May 1990.

122 G. Christopher Anderson, 'A Solution in Iron Solution?', *Nature* (1990) 345: 374.

123 As pointed out in R. D. Schuiling and P. Krijgsman, 'Enhanced Weathering', 349; and see further Schwartzman, *Life, Temparture*. Unfortunately for the gradualist conception of climate change, it is this primary geological counterforce to the accumulation of CO_2 in the atmosphere that fits the Lyellian scheme, with no known non-linearities or leaps.

124 Smith, *Pandora's Toolbox*, 168.

125 J. Gaillardet, B. Dupré, P. Louvat and C. J. Allègre, 'Global Silicate Weathering and CO_2 Consumption Rates Deduced from the Chemistry of Large Rivers', *Chemical Geology* (1999) 159: 21; Phil Renforth and Gideon Henderson, 'Assessing Ocean Alkalinity for Carbon Sequestration', *Reviews of Geophysics* (2017) 55: 640.

126 Lyla L. Taylor, Joe Quirk, Rachel M. S. Thorley et al., 'Enhanced Weathering Strategies for Stabilizing Climate and Averting Ocean Acidification', *Nature Climate Change* (2016) 6: 402–6. Cf. David J. Beerling, Euripides P. Kantzas, Mark R. Lomas et al., 'Potential for Large-Scale CO_2 Removal via Enhanced Rock Weathering with Croplands', *Nature* (2020) 583: 242–8; and further, with an exclusive focus on the US, David J. Beerling, Euripides P. Kantzas, Mark R. Lomas et al., 'Transforming US Agriculture for Carbon Removal with Enhanced Weathering', *Nature* (2025) 638: 425–34.

127 Walter Seifritz, 'CO_2 Disposal by Means of Silicates', *Nature* (1990) 345: 486.

128 K. S. Lackner and C. H. Wendt, 'Exponential Growth of Large Self-Reproducing Machine Systems', *Mathematical and Computer Modelling* (1995) 21: 55–81.

129 Ibid., 79. The auxon story is also told in Paul McKendrick, *Scrubbing the Sky: Inside the Race to Cool the Planet* (Vancouver: Figure 1, 2023), 15–17.

130 Thomas Bass, 'Robot, Build Thyself', *Discover Magazine*, October 1995.

131 For a history of this dream, see Minsoo Kang, *Sublime Dreams of Living Machines: The Automaton in the European Imagination* (Cambridge, Massachusetts: Harvard University Press, 2011).

132 Klaus S. Lackner, Christopher Wendt, Darryl P. Butt et al., ‘Carbon Dioxide Disposal in Carbonate Minerals’, *Energy* (1995) 20: 1153–70. A sligthly later paper is Greg H. Rau and Ken Caldeira, ‘Enhanced Carbon Dissolution: A Means of Sequestering Waste CO_2 as Ocean Bicarbonate’, *Energy Conversion and Management* (1999) 40: 1803–13.
133 Lackner et al., ‘Carbon Dioxide Disposal in Carbonate’, 1154.
134 ‘Our Portfolio’, Frontier, 2023.
135 ‘How It Works’, Lithos, 2023; cf. Mary Yap, ‘Introducing Lithos: Carbon Removal Using the Power of Enhanced Rock Weathering’, Lithos, 2022.
136 Violet George, ‘Frontier Makes Largest Carbon Removal Purchase from Lithos Carbon’, *Carbon Herald*, 8 December 2023.
137 ‘Overview’, Vesta, 2023.
138 ‘We Remove Greenhouse Gas Emissions from Wastewater’, CrewCarbon, 2023; Carolina Ortiz Guerrero, ‘Revolutionary Carbon Capture Method Integrated into Wastewater Treatment Plants’, *Remineralize the Earth*, 1 October 2023.
139 ‘Rocking CO_2 for a Livable Planet’, Arca, 2023.
140 ‘Technology’, Blue Planet Systems, 2023.
141 Fiekowsky, *Climate Restoration*, 87.
142 Ibid., 93.
143 Taylor et al., ‘Enhanced Weathering’, 402.
144 ‘Carbon Removal as Nature Intended’, InPlanet, 2023.
145 Mark Segal, ‘Google Signs its Largest Ever Carbon Removal Deal to Capture CO_2 in Crushed Rocks and Soil’, *ESG Today*, 12 December 2024.
146 Beerling et al., ‘Potential for’, 247; David J. Beerling, Dimitar Z. Epihov, Ilsa B. Kantola et al., ‘Enhanced Weathering in the US Corn Belt Delivers Carbon Removal with Agronomic Benefits’, *PNAS* (2024) 121: 1–10.
147 Qiyu Zhou, ‘Potential CO_2 Capture via Enhanced Weathering by Basaltic Sand Spreading on Golf Courses in the US’, *International Journal of Greenhouse Gas Control* (2024) 131: 1, 2.
148 Ibid., 5.
149 Jing Chun Feng, Liwei Sun and Jinyue Yan, ‘Carbon Sequestration via Shellfish Farming: A Potential Negative Emissions Technology’, *Renewable and Sustainable Energy Reviews* (2022) 171: 1–10; A. A. Alonso, X. A. Álvarez-Salgado and L. T. Antelo, ‘Assessing the Impact of Bivalve Aquaculture on the Carbon Circular Economy’, *Journal of Cleaner Production* (2021) 279: 1–12; Keisuke Nakayama, Yuki Kawahara, Yuki Kurimoto et al., ‘Effects of Oyster Aquaculture on Carbon Capture and Removal in a Tropical Mangrove Lagoon in Southwestern Taiwan’, *Science of the Total Environment* (2022) 838: 1–10.
150 Captura, ‘The Ocean Is the Answer’, 2023.
151 Ibid.; Erik Kobayashi-Solomon, ‘Captura’s Direct Ocean Capture Looks Promising’, *Forbes*, 15 February 2024.
152 Captura, ‘Equinor Leads $12M Series A Raise into Ocean-Based Carbon Removal Firm Captura’, 2023.
153 Justine Calma, ‘Meet the Fossil Fuel-Funded Startup Trying to Take CO_2 Out of the Ocean’, *The Verge*, 4 May 2023; Captura, ‘Captura Advances to the Top 20 Finalists in XPRIZE Carbon Removal Competition’, 8 May 2024.
154 Haroon S. Khesghi, ‘Sequestering Atmospheric Carbon Dioxide by Increasing Ocean Alkalinity’, *Energy* (1995) 20: 915–22.
155 Andres Oschlies, Lennart T. Bach, Rosalind E. M. Rickaby et al., ‘Climate Targets, Carbon Dioxide Removal, and the Potential Role of Ocean Alkalinity Enhancement’,

State of the Planet (2023) 2: 1–9. Natural climate solutions such as the restoration of mangroves – blue carbon, in other words – would similarly alkalinise waters: Mojtaba Fakhraee, Noah J. Planavsky and Christopher T. Reinhard, 'Ocean Alkalinity Enhancement through Restoration of Blue Carbon Ecosystems', *Nature Sustainability* (2023) 6: 1087–93.

156 See, for example, James Temple, 'Meta's Former CTO Has a New $50 Million Project: Ocean-Based Carbon Removal', *MIT Technology Review*, 6 June 2023; Carbon to Sea Initiative, 'We Must Remove 100's of Billions of Tons of CO_2 from the Atmosphere this Century', 2024.

157 Chelsea Harvey, 'Scientists Seek Approval for Geoengineering Project in Gulf of Maine', *ClimateWire*, 20 February 2025.

158 Justine Calma, 'Tech Companies Want to Capture Carbon at Paper Mills and Sewage Plants', *Verge*, 23 December 2024.

159 Brad Plumer and Raymond Zhong, 'They've Got a Plan to Fight Global Warming. It Could Alter the Oceans', *New York Times*, 23 September 2024.

160 Ebb Carbon, 'How We Do It: Electrochemical Ocean Alkalinity Enhancement', 2023.

161 'About', Equatic, 2023; Todd Woody, 'How Shocking the Ocean Could Turn It Into a Carbon Removal Powerhouse', *Bloomberg*, 2023; Corbin Hiar, 'First Ocean-Based Carbon Removal Plant Planned in Canada', *ClimateWire*, 18 June 2024; Laura Paddison, 'Can This Ocean-Based Carbon Plant Help Save the World? Some Scientists Are Raising Red Flags', CNN, 22 April 2024.

162 George, 'Top 10'; see further 'Restore the Climate. Heal the Ocean', Planetary Tech, 2024.

163 McKendrick, *Scrubbing*, 13.

164 L. E. Harris, 'Cornelis Drebbel: A Neglected Genius of Seventeenth Century Technology', *Transactions of the Newcomen Society* (1957) 31: 195–204. Drebbel's most far-sighted scheme by far was for a solar-powered district heating system in London. See ibid., 202.

165 The front of the boat appears to have been sloped steeply forwards and into the water so that the rowers could propel it below the surface; it would rise again when they stopped rowing. Rebecca Stetoff, *Submarines* (New York: Marshall Cavendish Benchmar, 2007), 22–3. On the design of the boat, see further, for example, Clark Emery, 'A Further Note on Drebbel's Submarine', *Modern Language Notes* (1942) 57: 451–5; J. W. van Spronsen, 'The Story Behind the Story: Cornelis Drebbel and Oxygen', *Journal of Chemical Education* (1977) 54: 157; Rachel M. Lance, *In the Waves: My Quest to Solve the Mystery of a Civil War Submarine* (New York: Penguin, 2020), 58.

166 Beerling, *The Emerald Planet*, 38; Lance, *In the Waves*, 59; Nick Lane, *Oxygen: The Molecule that Made the World* (Oxford: Oxford University Press, 2002), 4; Zbigniew Szydlo and Richard Brzezinski, 'A New Light on Alchemy', *History Today* (1997) 47: 21–2.

167 Lance, *In the Waves*, 59.

168 McKendrick, *Scrubbing*, 13.

169 Lance, *In the Waves*, 58; Lane, *Oxygen*, 4; John W. Severinghaus, 'Eight Sages Over Five Centuries Share Oxygen's Discovery', *Advances in Physiology Education* (2016) 40: 371; Emery, 'A Further Note', 455; van Spronsen, 'The Story', 157; Szydlo and Brzezinski, 'A New Light', 22; Harris, 'Cornelis Drebbel', 201. The latter solution could, however, with some stretch of the imagination – and this is what McKendrick relies on – be interpreted as a mechanism for scrubbing CO_2.

170 Lance, *In the Waves*, 59.

171 Robert Boyle, *New Experiments Physico-Mechanicall, Touching the Spring of Air, and its Effects* (Oxford: H. Hall, 1660), 364.
172 McKendrick, *Scrubbing*, 13.
173 Eugene A. Ramskill, 'Nuclear Submarine Habitability', *SAE Transactions* (1962) 70: 350–62; Mahdi Fasihi, Olga Efimova and Christian Breyer, 'Techno-Economic Assessment of CO_2 Direct Air Capture Plants', *Journal of Cleaner Production* (2019) 224: 959.
174 'Closing the Loop: Recycling Water and Air in Space', NASA, 2006; 'Recycling Water and Air', NASA,16 August 2019.
175 Klaus Lackner, Hans-Joachim Ziock and Patrick Grimes, 'Carbon Dioxide Extraction from Air: Is It an Option?', Los Alamos National Laboratory, 1999. On this paper as the origin of DAC, see for example, Eloy S. Sanz-Pérez, Christopher R. Murdock, Stephanie A. Didas and Christopher W. Jones, 'Direct Capture of CO_2 from Ambient Air', *Chemical Reviews* (2016) 116: 11842; Jialiang Sun, Meng Zhao, Liang Huang et al., 'Recent Progress on Direct Air Capture of Carbon Dioxide', *Current Opinion in Green and Sustainable Chemistry* (2023) 40: 1.
176 Lackner et al., 'Carbon Dioxide Extraction', 4.
177 Ibid., 8, 12; the story is told in McKendrick, *Scrubbing*, 20–1. On the sodium hydroxide solution, see further Frank S. Zeman and Klaus S. Lackner, 'Capturing Carbon Dioxide Directly from the Atmosphere', *World Resource Review* (2004) 16: 157–72.
178 Columbia Climate School, The Earth Institute, 'First Successful Demonstration of Carbon Dioxide Air Capture Technology Achieved by Columbia University Scientist and Private Company', 24 April 2007. See further Nicola Jones, 'Sucking It Up', *Nature* (2009) 458: 1095–6.
179 Ramskill, 'Nuclear Submarine', 355; 'Closing the Loop', NASA, 2. The material used in the sieves is zeolite.
180 Ramskill, 'Nuclear Submarine', 362.
181 See, for example, Yasser Abdullatif, Ahmed Sodiq, Namra Mir et al., 'Emerging Trends in Direct Air Capture of CO_2: A Review of Technology Options Targeting Net-Zero Emissions', *RSC Advances* (2023) 13: 5690–4; Muhammad Zeeshan, Michelle K. Kidder, Emily Pentzer et al., 'Direct Air Capture of CO_2: From Insights into the Current and Emerging Approaches to Future Opportunities', *Frontiers in Sustainability* (2023) 4: 1–11.
182 Soper, *What Is*, 132–3.
183 Samuel Castro-Pardo, Sohini Bhattacharya, Ram Manohar Yadav et al., 'A Comprehensive Overview of Carbon Dioxide Capture: From Materials, Methods to Industrial Status', *Materials Today* (2022) 60: 229; Howard Herzog, Jennifer Morris, Angelo Gurgel and Sergey Paltsev, 'Getting Real about Capturing Carbon from the Air', *One Earth* (2024) 7: 1477; Archer, *The Long*, 11; McKendrick, *Scrubbing*, 33–4.
184 'The CO_2 in air is commonly considered too dilute to justify its collection. Here we present a different point of view that suggests the opposite', Lackner et al. triumphantly declared in 'Carbon Dioxide', 5.
185 This is fully recognised even by David Keith (about whom see more below), 'Why Capture CO_2 from the Air?', *Science* (2009): 1655. Lackner, too, admits that 'low carbon dioxide concentration in air still results in a larger energy demand for air capture', even when he makes the most optimistic case for the thermodynamic viability of DAC: Klaus S. Lackner, 'The Thermodynamics of Direct Air Capture of Carbon Dioxide', *Energy* (2013) 50: 38. Cf. for example, Balint Simon, 'Material Flows and

Embodied Energy of Direct Air Capture: A Cradle-to-Gate Inventory of Selected Technologies', *Journal of Industrial Ecology* (2023): 658.

186 For example, Sun et al., 'Recent Progress', 7; Abdullatif et al., 'Emerging Trends', 5691–2.

187 Namely, 300 times more concentrated: Habib Azarabadi and Klaus S. Lackner, 'A Sorbent-Focused Techno-Economic Analysis of Direct Air Capture', *Applied Energy* (2019) 250: 960. Cf. Herzog et al., 'Getting Real', 1477.

188 See for example, ibid.; Sanz-Pérez et al., 'Direct Capture'; Castro-Pardo et al., 'A Comprehensive Overview'; Zeeshan et al., 'Direct Air'.

189 Quotation from Leslie Kaufman and Akshat Rathi, 'A Carbon-Sucking Startup Has Been Paralyzed by Its CEO', *Bloomberg*, 9 April 2021; R. P. Siegel, 'The Fizzy Math of Carbon Capture', *Grist*, 10 October 2018. McKendrick, *Scrubbing*, 36–47. On Chichilnisky taking credit for carbon markets, see for example, Graciela Chichilnisky and Kristen A. Sheeran, *Saving Kyoto: An Insider's Guide to How it Works, Why it Matters and What it Means For The Future* (London: New Holland Publishers, 2009), 6, 52–75, 108–111; Graciela Chichilnisky, 'Bio', n.d.

190 Candice Georgiadis, 'Female Disruptors: Graciela Chichilnisky of "Global Thermostat" on the Three Things You Need to Shake Up Your Industry', *Medium*, 20 November 2020.

191 Kaufman and Rathi, 'A Carbon-Sucking'.

192 'Global Thermostat Unveils One of the World's Largest Units for Removing Carbon Dioxide Directly from the Air', Global Thermostat, 4 April 2023; see also '"This Is What Confronting Climate Change Looks Like!"', Global Thermostat, 14 April 2023.

193 Maria Gallucci, 'A Buzzy New Carbon Removal Plant Is Catching and Releasing CO_2', *Canary Media*, 4 April 2023; Justin Calma, 'Why This New Plant Is Capturing Carbon Dioxide Just to Let It Back Out Again', *The Verge*, 6 April 2023.

194 For example, 'Global Thermostat Unveils Design with Top Engineering Firms for a Direct Air Capture System that Can Scale to Capture Millions of Tonnes of Carbon Dioxide Per Year', Global Thermostat, 11 December 2023; 'Global Thermostat Commissions First Containerized T-Series System for Multi-Tonne Direct Air Capture of Carbon Dioxide', Global Thermostat, 1 February 2024; Petya Trendafilova, 'Global Thermostat Unveils New Design for a Direct Air Capture System', *Carbon Herald*, 12 December 2023; 'Zero Carbon Systems Acquires Global Thermostat and its Best-in-Class Technology to Capture Carbon Dioxide from the Air', Global Thermostat, 22 May 2024.

195 Christoph Beuttler, Louise Charles and Jan Wurzbacher, 'The Role of Direct Air Capture in Mitigation of Anthropogenic Greenhouse Gas Emissions', *Frontiers in Climate* (2019) 1: 2.

196 Leslie Hook, 'How Capturing CO_2 from Air Can Combat Climate Change', *Financial Times*, 24 March 2019. Thunberg: Climeworks, 'Greta Thunberg at Climeworks' Direct Air Capture Plant in Hinwil', 10 March 2020. Cf. for example, Jon Gertner, 'The Tiny Swiss Company that Thinks It Can Help Stop Climate Change', *New York Times*, 12 February 2019.

197 To be exact, the Coca-Cola product in question was a type of mineral water: Beuttler et al., 'The Role', 3–4.

198 Simon Evans, 'The Swiss Company Hoping to Capture 1% of Global CO_2 Emissions by 2025', *Carbon Brief*, 22 June 2017.

199 McKendrick, *Scrubbing*, 92–4, 102.

200 Akshat Rathi, 'The World's First "Negative Emissions" Plant Has Begun Operation – Turning Carbon Dioxide into Stone', *Quartz*, 12 October 2017; 'Climeworks Takes

Another Major Step on Its Road to Building Gigaton DAC Capacity', Climeworks, 28 June 2022; 'Orca: The First Large-Scale Plant', Climeworks, 2024; Emily Ponntecorvo, 'Climeworks Is Building a Bigger Carbon Removal Plant – and Getting Some New Competition', *Grist*, 20 June 2022; McKendrick, *Scrubbing*, 97–102.

201 'Climeworks Switches on World's Largest Direct Air Capture Plant', Climeworks, 8 May 2024.

202 Observations by Carton.

203 The system was described in unusually transparent detail in David W. Keith, Geoffrey Holmes, David St. Angelo and Kenton Heidel, 'A Process for Capturing CO_2 from the Atmosphere', *Joule* (2018) 2: 1573–94; see further Carbon Engineering, 'Carbon Engineering's Large-Scale Direct Air Capture Breakthrough', 7 June 2018; Keith, 'Why Capture', 1655; Abdullatif et al., 'Emerging Trends', 5707; McKendrick, *Scrubbing*, 70–4.

204 For example, Molly Burgess, 'Carbon Engineer Named a Technology Pioneer', *Gas World*, 16 June 2020; Castro-Pardo et al., 'A Comprehensive Overview', 264.

205 An early profile of the triumvirate was Marc Gunther, 'Startups Have Figured Out How to Remove Carbon from the Air. Will Anyone Pay Them to Do It?', *Guardian*, 14 July 2015. For later surveys of the technologies used by the three pioneers and many lesser competitors, see Filippo Bisotti, Karl Anders Hoff, Anette Mathisen and Jon Hovland, 'Direct Air Capture (DAC) Deployment: A Review of the Industrial Deployment', *Chemical Engineering Science* (2024) 283: 1–17; Eryu Wang, Rahul Navik, Yihe Miao et al., 'Reviewing Direct Air Capture Startups and Emerging Technologies', *Cell Reports Physical Science* (2024) 5: 1–39.

206 Grant Faber, 'Direct Air Capture: Definition and Company Analysis', US Department of Energy Office of Fossil Energy and Carbon Management, 1 January 2025.

207 Klaus Lackner, 'These Machines Scrub Greenhouse Gases from the Air – An Inventor of Direct Air Capture Technology Shows How It Works', *The Conversation*, 18 January 2022; ABC15 Arizona, 'Mechanical Trees Capture CO2 at ASU Tempe Campus', YouTube, 19 April 2022; Zayna Syed, 'Can a Mechanical "Tree" Help Slow Climate Change? An ASU Researcher Built One to Find Out', *The Arizona Republic*, 22 April 2022.

208 Quotation from McKendrick, *Scrubbing*, 161; mass production in 2024: Violet George, 'Mechanical Trees to Be Used for Carbon Capture', *Carbon Herald*, 18 August 2022.

209 On the promises of this company, see James Temple, 'Startups Looking to Suck CO_2 from the Air Are Suddenly Luring Big Bucks', *MIT Technology Review*, 2 May 2019; John Reynolds, 'Carbon Tax Should Fund CO_2 Removal, Says CEO of "Mechanical Trees" Firm', *Irish Independent*, 21 June 2020; Leslie Hook, 'Startups Test Ideas to Suck CO2 from Atmosphere', *Financial Times*, 12 August 2020. A successor of Silicon Kingdom Holdings called Carbon Collect was listed as 'temporarily closed' as of this writing.

210 Emily Pontecorvo, 'This Carbon Removal Startup Is Eyeing a Major Price Milestone', *Heatmap News*, 19 March 2024 (emphasis in original). Founder: Charles Cadieu.

211 Ibid.; *Business Wire*, 'Spiritus Announces the First "Carbon Orchard" for Direct Air Capture, will Sequester 2 Megatons of Carbon Annually in Wyoming', 19 March 2024; Petya Trendafilova, 'Spiritus Announces Its First Large Scale DAC Facility with Up to 2 MT Capacity', *Carbon Herald*, 19 March 2024.

212 Elcke Vels, 'From Harmful to Valuable: Skytree Captures CO_2 for Greenhouse Farming', *Innovation Origins*, 9 November 2023.

213 Soletair Power, ‘To Increase Employee Productivity and Wellbeing, Companies Might Want to Ensure CO_2-Lean-Air as an Office Benefit’, 14 March 2022.

214 Wärtsila, ‘Every Breath You Take: Wärtsilä Promotes Clearer Minds, Champions Sustainability with CO_2 Capture at STH’, 12 March 2023.

215 Elliott T. Gall, Cem Sonat, William W. Nazaroff and Cise Unluer, ‘Investigating CO_2 Removal by Ca- and Mg-Based Sorbents with Application to Indoor Treatment’, *Building and Environment* (2016) 110: 161–172; cf. Abdullatif et al., ‘Emerging Trends’, 5709.

216 Shuangjun Li, Yifang Feng, Yuhan Li et al., ‘Critical Review on Mobile Direct Air Capture: Concept Expansion, Characteristic Description, and Performance Evaluation’, *Matter* (2024) 7: 912–18.

217 Petya Trendafilova, ‘New Direct Air Capture Plant that Runs on Nuclear Heat to Be Built in the UK’, *Carbon Herald*, 1 April 2023.

218 ‘Why HACCing?’, High Hopes Lab, 2024; Loz Blain, ‘High Hopes Claims Stratospheric Breakthrough in Direct Air CO_2 Capture’, *New Atlas*, 3 May 2021.

219 E. Bachman, Alexandra Tavasoli, T. Alan Hatton et al., ‘Rail-Based Direct Air Carbon Capture’, *Joule* (2022) 6: 1368–89.

220 ‘The World’s First Carbon-Negative Transportation’, CO2Rail, 2024.

221 One sample was given in Petya Trendafilova, ‘Top 20 Direct Air Capture Companies in 2023’, *Carbon Herald*, 12 May 2023; for a more complete list, see ‘DAC Coalition Members’, DAC Coalition, 2024. Australia: AspiraDAC. Kenya: Cella Mineral Storage.

222 CarbonCapture, ‘Project Bison’, 2024; Valerie Volcovici, ‘New Law Helps US Firm Launch Wyoming Direct Air Carbon Capture Project’, *Reuters*, 8 September 2022; Justine Calma, ‘The World’s Largest Carbon Removal Project Yet Is Headed for Wyoming’, *The Verge*, 23 September 2022.

223 Jonas Lee in Corbin Hiar, ‘Project Bison, a Large Carbon Removal Proposal, Faces Delays’, *E and E News*, 6 January 2023.

224 ‘Technology’, Infinitree, 2017.

225 ‘Carbon Removal That’s Sustainable at the Gigaton Scale’, RepAir, n.d.; Will Mathis, ‘Big Oil Backs Israeli Startup that Sucks CO_2 from the Atmosphere’, *Bloomberg*, 5 December 2022.

226 ‘Carbon Negative. Water Positive’, Avnos, 2024.

227 ‘About Svante’, Svante, 2024.

228 Mihrima Ozkan, ‘The Status of DAC Projects in the US’, *Chem* (2023) 9: 3381.

229 Eduard Garrido Ribó, Zhiwei Mao, Jacob S. Hirschi et al., ‘Implementing Vanadium Peroxides as Direct Air Capture Materials’, *Chemical Science* (2024) 15: 1700–13.

230 May Nyman in Alex Baumhardt, ‘Oregon State Scientists Discover Metal Capable of Removing Carbon Dioxide from Air’, *Oregon Public Broadcasting*, 19 March 2024.

231 Brandon Keim, ‘A Space Elevator for Carbon Dioxide’, *Wired*, 4 June 2007.

232 Bruce Einhorn, ‘Musk Wants SpaceX to Turn CO2 from Atmosphere into Rocket Fuel’, 14 December 2021.

233 Karl Marx and Friedrich Engels, *Manifesto of the Communist Party*, in Karl Marx, *The Revolutions of 1848* (London: Verso, 2010), 70.

9. (… and the Appendix of Caveats)

1 Jesse F. Abrams, Chris Huntingford, Mark S. Williamson et al., ‘Committed Global Warming Risks Triggering Multiple Climate Tipping Points’, *Earth’s Future* (2023) 11: 1–11.

2 Cf. for example, Christopher B. Field and Katharine J. Mach, ‘Rightsizing Carbon Dioxide Removal’, *Science* (2017) 356: 706–7; Oliver Perkins, Peter Alexander, Almut Ameth et al., ‘Toward Quantification of the Feasible Potential of Land-Based Carbon Dioxide Removal’, *One Earth* (2023) 6: 1646.

3 See, for example, O. Rueda, J. M. Mogollón, A. Tukker and L. Scherer, ‘Negative-Emissions Technology Portfolios to Meet the 1.5°C Target’, *Global Environmental Change* (2021) 67: 1–13; Jessica Strefler, Nico Bauer, Florian Humpenöder et al., ‘Carbon Dioxide Removal Technologies Are Not Born Equal’, *Environmental Research Letters* (2021) 16: 1–11.

4 Priyadarshi R. Shukla, Jim Skea, Raphael Slade et al. (eds), *Climate Change 2022: Mitigation of Climate Change: Contribution of Working Group III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change* (Cambridge: Cambridge University Press, 2022), 1264–5. Specifically, the IPCC lists average annual removals by 2100 of 8.96 gigatonnes for BECCS, 4.19 for tree-based removals and 1.02 for DAC.

5 Valérie Masson-Delmotte, Panmao Zhai, Hans-Otto Pörtner et al. (eds), ‘Summary for Policymakers’, in Masson-Delmotte et al., *Global Warming*, 17.

6 Pierre Friedlingstein, Michael O’Sullivan, Matthew W. Jones et al., ‘Global Carbon Budget 2023’, *Earth System Science Data* (2023) 15: 5327 (figure converted from gigatonnes carbon to gigatonnes CO_2). About 70 per cent of these emissions were from fossil fuel combustion, the rest from land use change, i.e. deforestation: ibid., 5319, 5323.

7 Karen D. Holl and Pedro H. S. Brancalion, ‘Tree Planting Is Not a Simple Solution’, *Science* (2020) 368: 580.

8 Carter M. Powis, Stephen M. Smith, Jan C. Minx and Thomas Gasser, ‘Quantifying Global Carbon Dioxide Removal Deployment’, *Environmental Research Letters* (2023) 18: 1–11.

9 Just over two: Stephen M. Smith, Oliver Geden, William F. Lamb et al. (eds), ‘The State of Carbon Dioxide Removal 2024. 2nd Edition’, University of Oxford, Smith School of Enterprise and the Environment, 2024, 124. Less than one tenth: Connor J. Nolan, Christopher B. Field and Katherine J. Mach, ‘Constraints and Enablers for Increasing Carbon Storage in the Terrestrial Biosphere’, *Nature Reviews Earth and Environment* (2021) 2: 437. Note that the latter – lower – estimate includes ‘avoided deforestation’, clearly not a form of removal.

10 Jean-Francois Bastin, Yelena Finegold, Claude Garcia et al., ‘The Global Tree Restoration Potential’, *Science* (2019) 365: 1–4 (figure recalculated from gigatonnes carbon to gigatonnes carbon dioxide).

11 Nolan et al., ‘Constraints and Enablers’, 440, 443. Note that most of these would come from tree planting; a second much-touted natural climate solution, the restoration of peatlands, or ‘rewetting’, has a far smaller potential. See ibid., 441; J. C. Doelman, W. Verhagen, E. Stehfest and D. P. van Duuren, ‘The Role of Peatland Degradation,

Protection and Restoration for Climate Change Mitigation in the SSP Scenarios', *Environmental Research: Climate* (2023) 2: 1–13.

12 Girardin et al., 'Nature-Based Solutions', 192; Seddon et al., 'Getting the Message', 1528; Stefanie Roe, Charlotte Streck, Robert Beach et al., 'Land-Based Measures to Mitigate Climate Change: Potential and Feasibility by Country', *Global Change Biology* (2021) 27: 6039. Tropical reforestation: 5 to 15 gigatonnes per year, according to Busch et al., 'Potential for Low-Cost'. A more modest estimate was that afforestation and reforestation could absorb a total of 160 to 280 gigatonnes in this century: Molly Hawes, 'Planting Carbon Storage', *Nature Climate Change* (2018) 8: 556. For another estimate at the higher end, see Sebastian Sonntag, Julia Pongratz, Christian H. Reick and Hauke Schmidt, 'Reforestation in a High-CO_2 World: Higher Mitigation Potential Than Expected, Lower Adaptation Potential Than Hoped for', *Geophysical Research Letters* (2016) 43: 6546–53.

13 Songbai Hong, Guodong Yin, Shilong Piao et al., 'Divergent Responses of Soil Organic Carbon to Afforestation', *Nature Sustainability* (2020) 3: 697; Ryan M. Bright, Micky Allen, Clara Antón-Fernandéz et al., 'Evaluating the Terrestrial Carbon Dioxide Removal Potential of Improved Forest Management and Accelerated Forest Conversion in Norway', *Global Change Biology* (2020) 26: 5101; David Lefebvre, Adrian G. Williams, Guy J. D. Kirk et al., 'Assessing the Carbon Capture Potential of a Reforestation Project', *Scientific Reports* (2021) 11: 1, 7; James Weber, James A. King, Nathan Luke Abraham et al., 'Chemistry-Albedo Feedbacks Offset Up to a Third of Forestation's CO_2 Removal Benefits', *Science* (2024) 383: 1.

14 Ryan M. Bright, Kaiguang Zhao, Robert B. Jackson and Francesco Cherubini, 'Quantifying Surface Albedo and Other Direct Biogeophysical Climate Forcings of Forestry Activities', *Global Change Biology* (2015) 21: 3246–66; Forrest Fleischman, Shishir Basant, Ashwini Chhtare et al., 'Pitfalls of Tree Planting Show Why We Need People-Centred Natural Climate Solutions', *BioScience* (2020) 70: 948–9; Deborah Lawrence, Michael Coe, Wayne Walker et al., 'The Unseen Effects of Deforestation: Biophysical Effects on Climate', *Frontiers in Forests and Global Change* (2022) 5: 2; Natalia Hasler, Christopher A. Williams, Vanessa Carrasco Denney et al., 'Accounting for Albedo Change to Identify Climate-Positive Tree Cover Restoration', *Nature Communications* (2024) 15: 1; Weber et al., 'Chemistry-Albedo Feedbacks', 1.

15 Simon L. Lewis, Charlotte E. Wheeler, Edward T. A. Mitchard and Alexander Koch, 'Regenerate Natural Forests to Store Carbon', *Nature* (2019) 568: 26; Hasler et al., 'Accounting for Albedo', 2; Weber et al., 'Chemistry-Albedo Feedbacks', 3; Nolan et al., 'Constraints and Enablers, 441. The obverse irony here is, of course, that deforestation at high latitudes has historically *cooled* the planet. See for example, Sonntag et al., 'Reforestation in a High-CO_2', 6549; Lawrence et al., 'The Unseen Effects', 1–2.

16 Eyal Rotenberg and Dan Yakir, 'Contribution of Semi-Arid Forests to the Climate System', *Science* (2010) 327: 451–4; Wei Cheng, John C. Moore, Long Cao et al., 'Simulated Climate Effects of Desert Irrigation Geoengineering', *Scientific Reports* (2017) 7: 1–10; Shani Rohatyn, Dan Yakir, Eyal Rotenberg and Yohay Carmel, 'Limited Climate Change Mitigation Potential through Forestation of the Vast Dryland Regions', *Science* (2022) 377: 1–4. Again, the irony here is that some historical desertification has had a cooling effect on the planet as a whole: see Rotenberg and Yakir, 'Contribution of Semi-Arid'.

17 Hasler et al., 'Accounting for Albedo'; H. Damon Matthews, Kirsten Zickfeld, Mitchell Dickau et al., 'Temporary Nature-Based Carbon Removal Can Lower Peak Warming in a Well-Below 2°C Scenario', *Communications Earth and Environment* (2022) 3: 6.

18 Hasler et al., ‘Accounting for Albedo’; Matthews et al., ‘Temporary Nature-Based’; Weber et al., ‘Chemistry-Albedo Feedbacks’. Or it might take more than one century after forest has been planted on dryland to offset the warming from the reduced albedo: Rafael Stern, Jonathan D. Muller, Eyal Rotenberg et al., ‘Photovoltaic Fields Largely Outperform Afforestation Efficiency in Global Climate Change Mitigation Strategies’, *PNAS Nexus* (2023) 2: 1–10.

19 Rohatyn et al., ‘Limited Climate’, 1, 2; Hasler et al., ‘Accounting for Albedo’, 4, 6; Joseph W. Veldman, Julie C. Aleman, Swanni T. Alvarado et al., ‘Comment on “The Global Tree Restoration Potential”’, *Science* (2019) 366: 2. Another optimistic estimate that knowingly makes the same error is Isabelle Ménard, Evelyne Thiffault, Werner A. Kurz and Jean-François Boucher, ‘Carbon Sequestration and Emission Mitigation Potential of Afforestation and Reforestation of Unproductive Territories’, *New Forests* (2023) 54: 1030.

20 On these changes and how they put a damper on removal potentials, see further William R. L. Anderegg, Anna T. Trugman, Grayson Badgley et al., ‘Climate-Driven Risks to the Climate Mitigation Potential of Forests’, *Science* (2020) 368: 1–9; Nathalie Seddon, ‘Harnessing the Potential of Nature-Based Solutions for Mitigating and Adapting to Climate Change’, *Science* (2022) 376: 3; Kangning Huang, ‘Urban Forests Facing Climate Risks’, *Nature Climate Change* (2022) 12: 893–4; Lefebvre et al., ‘Assessing the Carbon’, 8.

21 Natasha White and Zahra Hirji, ‘Canada’s Explosive Wildfires Have Damaged a Forest Carbon Offset Project’, *Bloomberg*, 26 June 2023. For the packaging, see the website of BigCoast Forest Climate Initiative.

22 Emily Pontecorvo and Shannon Osaka, ‘This Oregon Forest Was Supposed to Store Carbon for 100 Years. Now It’s On Fire’, *Grist*, 18 September 2020; Emily Pontecorvo and Shannon Osaka, ‘California Is Banking on Forests to Reduce Emissions. What Happens When They Go Up in Smoke?’, *Grist*, 27 October 2021.

23 Camilla Hodgson, ‘US Forest Fires Threaten Carbon Offsets as Company-Linked Trees Burn’, *Financial Times*, 3 August 2021; Winston Choi-Schagrin, ‘Wildfires Are Ravaging Forests Set Aside to Soak Up Greenhouse Gases’, *New York Times*, 23 August 2021; and cf. Buller, *The Value*, 82–3.

24 Grayson Badgley, Freya Chay, Oriana S. Chegwidden et al., ‘California’s Forest Carbon Offsets Buffer Pool Is Severely Undercapitalized’, *Frontiers in Forests and Global Change* (2022) 5: 1–15; Camilla Hodgson, ‘Wildfires Destroy Almost All Forest Carbon Offsets in 100-Year Reserve, Study Says’, *Financial Times*, 5 August 2022; and cf. Anderegg et al., ‘Climate-Driven Risks’, 4–5.

25 Ménard et al., ‘Carbon Sequestration’, 1013, 1025–6, 1028; Seddon, ‘Harnessing the Potential’, 4; Nolan et al., ‘Constraints and Enablers’, 440; Bernal et al., ‘Global Carbon’, 4–5, 7.

26 Such as the spruces of Norway: see Bright et al., ‘Evaluating the Terrestrial’.

27 Cf. Markusson, ‘Natural Carbon’, 3; Cook-Patton et al., ‘Protect, Manage’, 1031.

28 Nathalie Seddon, Beth Turner, Pam Berry et al., ‘Grounding Nature-Based Climate Solutions in Sound Biodiversity Science’, *Nature Climate Change* (2019) 9: 86; Pedro H. S. Brancilion and Karen D. Holl, ‘Guidance for Successful Tree Planting Initiatives’, *Journal of Applied Ecology* (2020) 57: 2351; Jesús Aguierre-Gutiérrez, Nicola Stevens and Erika Berenguer, ‘Valuing the Functionality of Tropical Ecosystems beyond Carbon’, *Trends in Ecology and Evolution* (2023) 38: 1110; Fleischmann et al., ‘Pitfalls of Tree’, 948; Seddon, ‘Harnessing the Potential’, 4. Monocultures are of course also most prone to catch diseases.

29 Anderegg et al., ‘Climate-Driven Risks’, 1; Augustin Prado and Niall Mac Dowell, ‘The Cost of Permanent Carbon Dioxide Removal’, *Joule* (2023) 7: 709.

30 Marc-André Parisien, Quinn E. Barber, Kelvin G. Hirsch et al., ‘Fire Deficit Increases Wildfire Risk for Many Communities in the Canadian Boreal Forest’, *Nature Communications* (2020) 11: 1–8; Oliver Perkins, ‘Toward Quantification’, 1642.

31 Kirsten Zickfeld, Alexander J. MacIsaac, Josep G. Canadell et al., ‘Net-Zero Approaches Must Consider Earth System Impacts to Achieve Climate Goals’, *Nature Climate Change* (2023) 13: 1299; Anderegg et al., ‘Climate-Driven Risks’, 7; Veldman et al., ‘Comment on “The Global”’, 2.

32 On California and the rest of the western US, see, for example, J. Aaron Hogan, Grant M. Domke, Kai Zhu et al., ‘Climate Change Determines the Sign of Productivity Trends in US Forests’, *PNAS* (2024) 121: 1–11; Holly J. Buck, Jay Fuhrman, David R. Morrow et al., ‘Adaptation and Carbon Removal’, *One Earth* (2020) 3: 427. For the general problem, cf. Jones et al., ‘Global Rise’, 10.

33 Brian Blankespoor, Susmita Dasgupta and Glenn-Marie Lange, ‘Mangroves as a Protection from Storm Surges in a Changing Climate’, *Ambio* (2017) 46: 478–91.

34 Nolan et al., ‘Constraints and Enablers’, 444. Cf. for example, Hammond et al., ‘Global Field’, 9.

35 Cf. Dennis Baldocchi and Josep Penuelas, ‘The Physics and Ecology of Mining Carbon Dioxide from the Atmosphere by Ecosystems’, *Global Change Biology* (2019) 25: 1194–5.

36 Cf. Matthews et al., ‘Temporary Nature-Based’, 2; Anderegg et al., ‘Climate-Driven Risks’, 4.

37 Fernanda Wenzel, ‘Illegal Timber from Amazon Carbon Credit Projects Reached Europe, US’, *Mongabay*, 16 December 2024.

38 Lydia J. Smith and Margaret S. Torn, ‘Ecological Limits to Terrestrial Biological Carbon Dioxide Removal’, *Climatic Change* (2013) 118: 91; Benjamin K. Sovacool, Chad M. Baum and Sean Low, ‘Climate Protection or Privilege? A Whole Systems Justice Milieu of Twenty Negative Emissions and Solar Geoengineering Technologies’, *Political Geography* (2022) 97: 10; Strefler et al., ‘Carbon Dioxide’, 4; Fleischman, ‘Pitfalls of Tree’, 949.

39 As noted in Baldocchi and Penuelas, ‘The Physics and Ecology’, 1194, regarding Griscom et al., ‘Natural Climate’. In another – critical – calculation, removing one *year’s* worth of global emissions (as of the early 2020s) would necessitate the requisitioning of an area as large as that of the US, the UK, China and Russia combined for forest plantations. Aguierre-Gutiérrez et al., ‘Valuing the Functionality’, 1109.

40 Nolan et al., ‘Constraints and Enablers’, 442.

41 Lewis et al., ‘Regenerate Natural’, 26.

42 Jonathan C. Doelman, Elke Stehfest, Detlef P. van Vuuren et al., ‘Afforestation for Climate Change Mitigation: Potentials, Risks and Trade-Offs’, *Global Change Biology* (2020) 26: 1583. The same outsourcing to the global South happens in the IAM-based Roe et al., ‘Land-Based Measures’, 6043, 6051; and cf. Strefler et al., ‘Carbon Dioxide’, 6, 8.

43 As pointed out in Eike Luedeling, Jan Börner, Wulf Amelung et al., ‘Forest Restoration: Overlooked Constraints’, *Science* (2019) 366: 315.

44 Ulrich Kreidenweis, Florian Humpenöder, Miodrag Stefanović et al., ‘Afforestation to Mitigate Climate Change: Impacts on Food Prices under Consideration of Albedo Effects’, *Environmental Research Letters* (2016) 11: 1–11.

45 Ibid., 8.

46 Doelman et al., ‘Afforestation for Climate’, 1585, 1587, 1588. Hence these modellers did not advocate afforestation but demonstrated its trade-offs.

47 Ruth Delzeit, Julia Pongratz, Julia M. Schneider et al., ‘Forest Restoration: Expanding Agriculture’, *Science* (2019) 366: 316; Holl and Brancalion, ‘Tree Planting’, 581; Doelman et al., ‘Afforestation for Climate’, 1576.

48 Robert B. Jackson, Esteban G. Jobbágy, Roni Avissar et al., ‘Trading Water for Carbon with Biological Carbon Sequestration’, *Science* (2005) 310: 1944–7; Pete Smith, Justin Adams, David J. Beerling et al., ‘Impacts of Land-Based Greenhouse Gas Removals on Ecosystem Services and the United Nations Sustainable Development Goals’, *Annual Review of Environment and Resources* (2019) 55: 5–6; Douglas Shell, Aida Bargués-Tobella, Ulrik Ilstedt et al., ‘Forest Restoration: Transformative Trees’, *Science* (2019) 366: 316; Kate Dooley, Ellycia Harrould-Kolieb and Anita Talberg, ‘Carbon-Dioxide Removal and Biodiversity: A Threat Identification Network’, *Global Policy* (2021) 12: 37; Smith and Torn, ‘Ecological Limits’, 92.

49 Cheng et al., ‘Simulated Climate’, 7.

50 Smith and Torn, ‘Ecological Limits’, 91–2, 98.

51 On the defensive after years of multi-pronged critique, adherents strove to solidify progressive principles for natural climate solutions, the first of which would be that they ‘sustain biodiversity’; and if they do not – if they sequester more carbon at the expense of plant diversity native to the ecosystem – they ‘would not qualify’ as such. Peter Woods Ellis, Aaron Marr Page, Stephen Wood et al., ‘The Principles of Natural Climate Solutions’, *Nature Communications* (2024) 15: 4. Similar principles applied to everything from respect for the spirituality of indigenous people to allowing no substitution for emissions reductions. Ibid., 7, 5. This came across as a wish list for perfectly virtuous natural climate solutions, bordering on an idealised *definition* of them.

52 William J. Bond, Nicola Stevens, Guy F. Midgley and Caroline E. R. Lehmann, ‘The Trouble with Trees: Afforestation Plans for Africa’, *Trends in Ecology and Evolution* (2019) 34: 963–5; Catherine L. Parr, Mariska te Beest and Nicola Stevens, ‘Conflation of Reforestation with Restoration is Widespread’, *Science* (2024) 383: 698–701; Seddon et al., ‘Getting the Message’, 1531; Seddon, ‘Harnessing the Potential’, 4; Veldman et al., ‘Comment on “The Global”’, 2; Dooley et al., ‘Carbon-Dioxide Removal’, 37; Fleischman et al., ‘Pitfalls of Tree’, 948; Brancilion and Holl, ‘Guidance for Successful’, 2351–2. Those grasslands store carbon in the soil, on some accounts far more effectively than imposed plantations would do. For all the follies of afforesting African savannas, see Bond et al., ‘The Trouble with’; Parr et al., ‘Conflation of Reforestation’.

53 Sebastiaan Luyssaert, E.-Detlef Schulze, Annett Börner et al., ‘Old-Growth Forests as Global Carbon Sinks’, *Nature* (2008) 455: 213–15; Polly C. Buotte, Beverly E. Law, William J. Ripple and Logan T. Berner, ‘Carbon Sequestration and Biodiversity Co-Benefits of Preserving Forests in the Western United States’, *Ecological Applications* (2024) 30: 1–11.

54 Timothy E. Crews, Wim Carton and Lennart Olsson, ‘Is the Future of Agriculture Perennial? Imperatives and Opportunities to Reinvent Agriculture by Shifting from Annual Monocultures to Perennial Polycultures’, *Global Sustainability* (2018) 1: 1–18.

55 Deprez et al., ‘Sustainability Limits’, 485; Seddon, ‘Harnessing the Potential’, 1. Cf. the critique of the optimistic estimates in Nolan et al., ‘Constraints and Enablers’, 441; Susan C. Cook-Patton, Sara M. Leavitt, David Gibbs et al., ‘Mapping Carbon Accumulation Potential from Global Natural Forest Regrowth’, *Nature* (2020) 585: 548.

56 If every human being planted one tree, the 8 billion trees would – after maturation – remove the equivalent of 43 hours of emissions from the world economy, as of the early

2020s. David T. Ho, ‘Carbon Dioxide Removal Is an Ineffective Time Machine’, *Nature* (2023) 616: 9.

57 Cf. Zickfeld et al., ‘Net-Zero Approaches’, 1298; Baldocchi and Penuelas, ‘The Physics and Ecology’, 1191, 1194; Bond et al., ‘The Trouble with Trees’, 964.

58 Bright et al., ‘Evaluating the Terrestrial’, 5101. Somewhat similarly, annual sequestration from maximum forestation in Quebec would take out the equivalent of 18 per cent of the annual emissions from that province: Ménard et al., ‘Carbon Sequestration’, 1030.

59 The greatest fans of trophic rewilding have suggested that it could take out 6 gigatonnes per year, but this appears to be wildly wishful thinking: Schmitz and Sylvén, ‘Animating the Carbon’, 10; Schmitz et al., ‘Trophic Rewilding’, 329.

60 Ethan Duvall, Elizabeth le Roux, Heidi Pearson et al., ‘Resisting the Carbonization of Animals as Climate Solutions’, *Nature Climate Change* (2024) 14: 892.

61 For example, Mathilde Fajardy, Piera Patrizio, Habiba Ahut Daggash and Nial Mac Dowell, ‘Negative Emissions: Priorities for Research and Policy Design’, *Frontiers in Climate* (2019) 1: 3. See also Simon L. Lewis et al., ‘Comment on “The Global Tree Restoration Potential”’, *Science* (2019) 366: 2.

62 The difference means, however, that BECCS is less land-hungry than afforestation per quantum of CO_2 removed, as the removal capacity of BECCS is renewed on the same patch of land: Kreidenweis, ‘Afforestation to Mitigate’, 2.

63 Isabela Butnar, Pei-Hao Li, Neil Strachan et al., ‘A Deep Dive into the Modelling Assumptions for Biomass with Carbon Capture and Storage (BECCS): A Transparency Exercise’, *Environmental Research Letters* (2020) 15: 9; Felix Creutzig, Karl-Heinz Erb, Helmut Haberl et al., ‘Considering Sustainability Thresholds for BECCS in IPCC and Biodiversity Assessments’, *GCB Bioenergy* (2021) 13: 511; Rueda, ‘Negative-Emissions Technology’, 8.

64 Lena R. Boysen, Wolfgang Lucht and Dieter Gerten, ‘Trade-Offs for Food Production, Nature Conservation and Climate Limit the Terrestrial Carbon Dioxide Removal Potential’, *Global Change Biology* (2017) 23: 4307; Xin Zhao, Bryan K. Mignone, Marshall A. Wise and Haewon C. McJeon, ‘Trade-Offs in Land-Based Carbon Removal Measures under 1.5°C and 2°C Futures’, *Nature Communications* (2024) 15: 9; Dooley et al., ‘Carbon-Dioxide Removal’, 38.

65 For some modelling following this imperative, see S. V. Hanssen, V. Daioglou, Z. J. N. Steinmann et al., ‘The Climate Change Mitigation Potential of Bioenergy with Carbon Capture and Storage’, *Nature Climate Change* (2020) 10: 1023–9.

66 Jennifer Cronin, Florian Zabel, Olivier Dessens and Gabrial Anandarajah, ‘Land Suitability for Energy Crops under Scenarios of Climate Change and Land-Use’, *GCB Bioenergy* (2020) 12: 654; Philipp Günther and Felix Ekardt, ‘Human Rights and Large-Scale Carbon Dioxide Removal: Potential Limits to BECCS and DACCS Deployment’, *Land* (2022) 11: 12.

67 Perkins, ‘Toward Quantification’, 1639. Cf. for example, Vera Heck, Dieter Gerten, Wolfgang Lucht and Alexander Popp, ‘Biomass-Based Negative Emissions Difficult to Reconcile with Planetary Boundaries’, *Nature Climate Change* (2018) 8: 151–5.

68 For example, Keywan Riahi, Detlef P. van Vuuren, Elmar Kriegler et al., ‘The Shared Socioeconomic Pathways and their Energy, Land Use, and Greenhouse Gas Emissions Implications: An Overview’, *Global Environmental Change* (2017) 42: 165; R. C. Henry, K. Engström, S. Olin et al., ‘Food Supply and Bioenergy Production within the Global Cropland Planetary Boundary’, *PLOS ONE* (2018) 13: 1–17; Pete Smith, Steven J. Davis, Felix Creutzig et al., ‘Biophysical and Economic Limits to Negative CO_2 Emissions’, *Nature Climate Change* (2015) 6: 46; Tomoko Hasegawa, Shichiro

Fujimori, Stefan Frank et al., 'Land-Based Implications of Early Climate Actions without Global Net-Negative Emissions', *Nature Sustainability* (2021) 4: 1056. In short, 'more arable lands become available for bioenergy if less land is required for conventional agriculture.' Hanssen et al., 'The Climate Change', 1026.

69 Phil Williamson, 'Scrutinize CO_2 Removal Methods', *Nature* (2016) 530: 154; P. A. Turner, C. B. Field, D. B. Lobell et al., 'Unprecedented Rates of Land-Use Transformation in Modelled Climate Change Mitigation Pathways', *Nature Sustainability* (2018) 1: 240–1; Daniel Quiggin, 'BECCS Deployment: The Risks of Policies Forging ahead of the Evidence', Chatham House, October 2021, 8.

70 Williamson, 'Scrutinize CO_2', 154.

71 Deprez et al., 'Sustainable Limits', 484.

72 Kevin Anderson and Glen Peters, 'The Trouble with Negative Emissions', *Science* (2016) 354: 183; Christopher B. Field and Katharine J. Mach, 'Rightsizing Carbon Dioxide Removal', *Science* (2017) 356: 707; Smith et al., 'Biophysical and Economic', 46.

73 Michael Obersteiner, Johannes Bednar, Fabian Wagner et al., 'How to Spend a Dwindling Greenhouse Gas Budget', *Nature Climate Change* (2017) 8: 8; Kate Dooley, Peter Christoff and Kimberley A. Nicholas, 'Co-Producing Climate Policy and Negative Emissions: Trade-Offs for Sustainable Land-Use', *Global Sustainability* (2018) 1: 5–6; Perkins et al., 'Toward Quantification', 1639. It could amount to 'a biogeochemical shift in the terrestrial biosphere which is, in absolute terms, even larger than that already produced' by homo sapiens throughout its history as a species. Vera Heck, Dieter Gerten, Wolfgang Lucht and Lena R. Boysen, 'Is Extensive Terrestrial Carbon Dioxide Removal a "Green" Form of Geoengineering? A Global Modelling Study', *Global and Planetary Change* (2016) 137: 123.

74 Turner et al., 'Unprecedented Rates'.

75 K. Dooley, H. Keith, A. Larson et al., *The Land Gap Report 2022*, University of Melbourne, Griffith University, CIFOR et al., November 2022. See further Kate Dooley, Kristine Lund Christianssen, Jens Friis Lund and Wim Carton, 'Over-Reliance on Land for Carbon Dioxide Removal in National Climate Pledges', *Nature Communications* (2024) 15: 1–10. Oxfam similarly calculated that 80 per cent of all farmlands in the world would need to be covered in trees to achieve net-zero targets by 2020. Aditi Sen and Nafkote Dabi, 'Tightening the Net: Net Zero Climate Targets – Implications for Land and Food Equity', Oxfam International, August 2021.

76 Ottomar Edenhofer, Ramón Richs-Madruga, Youba Sokona et al., *Climate Change 2014: Mitigation of Climate Change. Working Group III Contribution to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change* (Cambridge: Cambridge University Press, 2014), 448. Dutch scientists exemplify this preference for southern land in Hanssen et al., 'The Climate Change'. From English and German pens: 'Sub-Saharan Africa, Australia, Brazil and South East Asia currently have the greatest areas potentially suitable for energy crops.' Cronin et al., 'Land Suitability', 661. For the rare analysis applying concepts from critical political economy to BECCS, see Pamela McElwee, 'Advocating Afforestation, Betting on BECCS: Land-Based Negative Emissions Technologies (NETs) and Agrarian Livelihoods in the Global South', *The Journal of Peasant Studies* (2023): 194–5.

77 Gregor Jaschke and Frank Biermann, 'The Policy Discourse on Negative Emissions, Land-Based Technologies, and the Global South', *Global Environmental Change* (2022) 75: 1–10.

78 Cf. ibid., 2; Wim Carton, Adeniyi Asiyanbi, Silke Beck et al., 'Negative Emissions and the Long History of Carbon Removal', *WIREs Climate Change* (2020) 11: 11–12.

79 Cronin et al., ‘Land Suitability’, 654.

80 Glen P. Peters and Oliver Geden, ‘Catalysing a Political Shift from Low to Negative Carbon’, *Nature Climate Change* (2017) 7: 620–1. Another favoured source of biomass for the UK and other parts of the imperial core is, unsurprisingly, Brazil: Mathilde Fajardy, Solene Chiquier and Niall Mac Dowell, ‘Investigating the BECCS Resource Nexus: Delivering Sustainable Negative Emissions’, *Energy and Environmental Science* (2018) 11: 3416, 3418. ‘The availability of biomass is unevenly distributed; some of the world regions with the greatest resource requirements have comparatively low resource availability. The global trade of biomass, therefore, has an important role to play’ – but as an afterthought, this ‘raises issues around equity’. (And the supply chains could be victims of ‘political instability’ among the southern suppliers.) Clair Gough, Samira Garcia-Freites, Christopher Jones et al., ‘Challenges to the Use of BECCS as a Keystone Technology in Pursuit of 1.5°C’, *Global Sustainability* (2018) 1: 4.

81 David J. Tenenbaum, ‘Food vs. Fuel: Diversion of Crops Could Cause More Hunger’, *Environmental Health Perspectives* (2008) 116: 256. On the biofuel boom and its impacts on food prices in this period, see further Lester R. Brown, *Full Planet, Empty Plates: The New Geopolitics of Food Scarcity* (London: W. W. Norton, 2012), 9–10, 36–44; Desirée A. L. Quagliarotti, ‘Some Reflections on the Causes and Effects of the Global Food Crisis’, *Global Environment* (2012) 10: 192–5.

82 See John Bohstedt, ‘Food Riots and the Politics of Provisions from Early Modern Europe and China to the Food Crisis of 2008’, *The Journal of Peasant Studies* (2016) 43: 1035–6, 1044–58.

83 See further Brown, *Full Planet*.

84 Jevgenyi Bluwstein and Connor Cavanagh, ‘Rescaling the Land Rush? Global Political Ecologies of Land Use and Cover Change in Key Scenario Archetypes for Achieving the 1.5°C’, *The Journal of Peasant Studies* (2023) 50: 262–94.

85 See for example, Ilan Pappe, *The Ethnic Cleansing of Palestine* (London: Oneworld, 2006), 225–34; Saree Makdisi, *Tolerance Is a Wasteland: Palestine and the Culture of Denial* (Oakland: University of California Press, 2022), 18–46; Ghada Sasa, ‘Oppressive Pines: Uprooting Israeli Green Colonialism and Implanting Palestinian A’wna’, *Politics* (2023) 43: 219–35. Note that the Zionist entity is here the scientifically accurate term for the agent in question, as it was the Jewish National Fund that organised the planting of trees. ‘What could be more innocent than planting trees? What could be more evocative of a claim to be nurturing and developing the land?’ The Jewish National Fund ‘successfully repackaged itself as an environmental organisation involved in greening the planet and saving us all from global warming’. Makdisi, *Tolerance Is*, 35.

86 Per Sandström, Neil Cory, Johan Svensson et al., ‘On the Decline of Ground Lichen Forests in the Swedish Boreal Landscape: Implications for Reindeer Husbandry and Sustainable Forest Management’, *Ambio* (2017) 45: 414–29.

87 McElwee, ‘Advocating Afforestation’, 10–13; Bluwstein and Cavanagh, ‘Rescaling the Land’, 264–5, 274–5, 286; Creutzig et al., ‘Considering Sustainability’, 513.

88 Sigmund Freud, *The Interpretation of Dreams* (Oxford: Oxford University Press, 2008 [1899]), 43–4 (emphasis in original).

89 Cf. Dooley et al., *The Land Gap*, 26.

90 Although natural climate solutions primarily centre on living biological matter: standing forests.

91 Lauren Sneyd, ‘“We Eat What We Have, Not What We Want”: The Policy Effects of Food Riots and Eating after the 2008 Crisis in Cameroon’, in Naomi Hossain and Patta

Scott-Villiers (eds), *Food Riots, Food Rights and the Politics of Provisions* (London: Routledge, 2017), 98–115.

92 Butnar et al., ‘A Deep Dive’, 9–10; Turner et al., ‘Unprecedented Rates’, 242–3.

93 Hannah Ritchie, ‘If the World Adopted a Plant-Based Diet, We Would Reduce Global Agricultural Land use from 4 to 1 Billion Hectares’, *Our World in Data*, 4 March 2021.

94 Ibid.; Peter Alexander, Mark D. A. Rounsevell, Claudia Dislich et al., ‘Drivers for Global Agricultural Land Use Change: The Nexus of Diet, Population, Yield and Bioenergy’, *Global Environmental Change* (2015) 35: 139, 141; Peter Alexander, Calum Brown, Almut Arneth et al., ‘Human Appropriation of Land for Food: The Role of Diet’, *Global Environmental Change* (2016) 41: 89. The fact that some pasture is unsuitable for crops does not fundamentally alter this picture.

95 Alexander et al., ‘Human Appropriation’, 91–4.

96 Alexander et al., ‘Drivers for Global’, 142–4.

97 For example, Helmut Haberl, Karl-Heinz Erb, Fridolin Krausmann et al., ‘Global Bioenergy Potentials from Agricultural Land in 2050: Sensitivity to Climate Change, Diets and Yields’, *Biomass and Bioenergy* (2011) 35: 4757–69; Thomas W. R. Powell and Timothy M. Lenton, ‘Future Carbon Dioxide Removal *via* Biomass Energy Constrained by Agricultural Efficiency and Dietary Trends’, *Energy and Environmental Science* (2012) 8: 1–18; Boysen et al., ‘Trade-Offs for Food’, 4311–16.

98 Oscar Rueda, José M. Mogollón, Fabian Stenzel et al., ‘A Protein Transition Can Free Up Land to Tap Vast Energy and Negative Emissions Potentials’, *One Earth* (2024) 7: 295–7. An alternative use of this freed-up land would, of course, be forestation and rewilding. Cf. Griscom et al., ‘National Mitigation’, 5; Cook-Patton et al., ‘Mapping Carbon’, 548; Cromsigt et al., ‘Trophic Rewilding’, 8. One vision is to terminate both the fossil economy and the meat industry, use the freed-up land from the latter to remove the stains from the former and then, once positive emissions from both the present and the past have been eradicated, quit BECCS and return the land to the wild. Rueda et al., ‘A Protein Transition’, 300.

99 See for example, Rueda et al., ‘A Protein Transition’, 294, 298–9; Alexander et al., ‘Drivers for Global’, 145; Henry et al., ‘Food Supply’, 11; Monika Zurek, Aniek Hebinck and Odirilwe Selomane, ‘Climate Change and the Urgency to Transform Food Systems’, *Science* (2022) 1416–21.

100 Siqing Xu, Rong Wang, Thomas Gasser et al., ‘Delayed Use of Bioenergy Crops Might Threaten Climate and Food Security’, *Nature* (2022) 609: 299.

101 Heck et al., ‘‘Biomass-Based Negative’, 153. Cf. Mathilde Fajardy and Niall Mac Dowall, ‘Can BECCS Deliver Sustainable and Resource Efficient Negative Emissions?’, *Energy and Environmental Science* (2017) 10: 1390, 1408–9.

102 Fabian Stenzel, Peter Greve, Wolfgang Lucht et al., ‘Irrigation of Biomass Plantations May Globally Increase Water Stress More than Climate Change’, *Nature Communications* (2021) 12: 1–9.

103 Smith and Torn, ‘Ecological Limits’, 95, 98.

104 Christian Hof, Alke Voskamp, Matthias F. Biber et al., ‘Bioenergy Cropland Expansion May Offset Positive Effects of Climate Change Mitigation for Global Vertebrate Diversity’, *PNAS* (2018) 115: 13294–9. Cf. Meyer and Trisos, ‘Ecological Impacts’, 1616.

105 Cf. Anderson et al., ‘Planning for Change’, 117; Meyer et al., ‘Risks to Biodiversity’, 8–9.

106 Cf. Heck, ‘Is Extensive’, 129.

107 On the case of Sweden, see Sabine Fuss and Filip Johnsson, ‘The BECCS Implementation Gap: A Swedish Case Study’, *Frontiers in Energy Research* (2021) 8:

1–18; Lars Zetterberg, Filip Johnsson and Kenneth Möllersten, ‘Incentivizing BECCS: A Swedish Case Study’, *Frontiers in Climate* (2021) 3: 1–16. For an assessment of the (limited) European potential from existing bioenergy plants, see Anton Arbman Hansing and Mathias Fridahl, ‘European and Swedish Point Sources of Biogenic Carbon Dioxide’, in Mathias Fridahl (ed.), *Bioenergy with Carbon Capture and Storage: From Global Potentials to Domestic Realities* (Stockholm and Brussels: Fores and European Liberal Forum, 2018), 30–43.

108 But not even that was guaranteed: the emission outcomes of biomass use ultimately depend on where and how it is harvested, what that does to the land, and so on. See Anna Harper, Tom Powell, Peter Cox et al. ‘Land-Use Emissions Play a Critical Role in Land-Based Mitigation for Paris Climate Targets’, *Nature Communications* (2018) 9: 1–13.

109 European Academies’ Science Advisory Council, ‘Forest Bioenergy Update: BECCS and Its Role in Integrated Assessment Models’, February 2022.

110 Cf. Mathilde Fajardy and Niall Mac Dowall, ‘The Energy Return on Investment of BECCS: Is BECCS a Threat to Energy Security?’, *Energy and Environmental Science* (2018) 11: 1587, 1589; Lorenzo Rosa, Daniel L. Sanchez and Marco Mazzotti, ‘Assessment of Carbon Dioxide Removal Potential *via* BECCS in a Carbon-Neutral Europe’, *Energy and Environmental Science* (2021) 14: 3086–97; Günther and Ekardt, ‘Human Rights’, 3–4; Fajardy and Mac Dowell, ‘Can BECCS’, 1393.

111 Zhipin Ai, Naota Hanasaki, Vera Heck et al., ‘Global Bioenergy with Carbon Capture and Storage Potential Is Largely Constrained by Sustainable Irrigation’, *Nature Sustainability* (2021) 4: 887.

112 Johanna Braun, Costanze Werner, Dieter Gerten et al., ‘Multiple Planetary Boundaries Preclude Biomass Crops for Carbon Capture and Storage Outside of Agricultural Areas’, *Communications Earth and Environment* (2025), 6: 102.

113 Deprez et al., ‘Sustainability Limits’, 484–5; and cf. Creutzig et al., ‘Considering Sustainability’, 512–13; Stephanie Roe, Charlotte Streck, Robert Beach et al., ‘Land-Based Measures to Mitigate Climate Change: Potential and Feasibility by Country’, *Global Change Biology* (2021) 27: 6041.

114 For this relation in the case of BECCS, cf. Paul C. Stoy, Selena Ahmed, Meghan Jarchow et al., ‘Opportunities and Trade-Offs among BECCS and the Food, Water, Energy, Biodiversity, and Social Systems Nexus at Regional Scales’, *BioScience* (2018) 68: 109.

115 Vera Heck, Jonathan F. Donges and Wolfgang Lucht, ‘Collateral Transgression of Planetary Boundaries due to Climate Engineering by Terrestrial Carbon Dioxide Removal’, *Earth System Dynamics* (2016) 7: 792.

116 For one typical example of its downgrading, see Rueda et al., ‘Negative-Emissions Technologies’, 7–8.

117 Cf. Kevin Anderson, Holly Jean Buck, Lili Fuhr et al., ‘Controversies of Carbon Dioxide Removal’, *Nature Reviews Earth and Environment* (2023) 4: 811.

118 Cf. Smith et al., ‘Impacts of Land-Based’, 14.

119 Smith, ‘Soil Carbon’, 7; Jaschke and Biermann, ‘The Policy Discourse’, 2.

120 Martin Belam, ‘Make America Rake Again: Finland Baffled by Trump’s Forest Fire Raking Claim’, *Guardian*, 19 November 2018.

121 Abby Rabinowitz and Amanda Simson, ‘This New York Town Doesn’t Want to Be a Climate Experiment’, *Grist*, 6 December 2024.

122 Shukla et al. (eds), *Climate Change 2022*, 790; Smith, ‘Soil Carbon’, 4, 6, 7, 9; Prado and Mac Dowell, ‘The Cost’, 707.

123 On this general state of knowledge, or rather ignorance, see, for example, National Academies of Sciences, Engineering, and Medicine, *A Research Strategy for Ocean-Based Carbon Dioxide Removal and Sequestration* (Washington, DC: The National Academies Press, 2022); James Temple, 'Why Using the Oceans to Suck up CO_2 Might Not Be as Easy as Hoped', *MIT Technology Review*, 30 March 2022.

124 Bridget Huber, 'Could Seaweed Be the "Fastest and Least Expensive" Tool to Fight Climate Change?', *National Geographic*, 1 June 2023.

125 Mike Schroepfer – former chief technology officer of Meta – of Carbon to Sea in Temple, 'Meta's Former CTO'.

126 Temple, 'Companies Hoping'.

127 Aurora M. Ricart, Dorte Krause-Jensen, Kasper Hancke et al., 'Sinking Seaweed in the Deep Ocean for Carbon Neutrality Is Ahead of Science and Beyond the Ethics', *Environmental Research Letters* (2022) 17: 3–4.

128 The story of the early history of ocean removal is summarized in Aaron L. Strong, John J. Cullen and Sallie W. Chisholm, 'Ocean Fertilization: Science, Policy, and Commerce', *Oceaonography* (2009) 22: 236–61. See also Sallie W. Chisholm, Paul G. Falkowski and John J. Cullen, 'Dis-Crediting Ocean Fertilization', *Science* (2001) 294: 309–11; Zach Horton, 'Going Rogue or Becoming Salmon? Geoengineering Narratives in Haida Gwaii', *Cultural Critique* (2017) 97: 128–66.

129 Climate Foundation, 'Invest in Our Oceans', n.d.

130 Miranda Boettcher, Kerryn Brent, Holly Jean Buck et al., 'Navigating Potential Hype and Opportunity in Governing Marine Carbon Removal', *Frontiers in Climate* (2021) 3: 2–3; Julianne DeAngelo, Benjamin T. Saenz, Isabella B. Arzeno-Soltero et al., 'Economic and Biophysical Limits to Seaweed Farming for Climate Change Mitigation', *Nature Plants* (2023) 9: 45; Ricart et al., 'Sinking Seaweed', 2; De Pryck and Boettcher, 'The Rise, Fall', 7.

131 Isabella B. Arzeno-Soltero, Benjamin T. Saenz, Christina A. Frieder et al. 'Large Global Variations in the Carbon Dioxide Removal Potential of Seaweed Farming Due to Biophysical Constraints', *Communications Earth and Environment* (2023) 4: 6. Similar figures are given in Guang Gao, John Beardall, Peng Jin et al., 'A Review of Existing and Potential Blue Carbon Contributions to Climate Change Mitigation in the Anthropocene', *Journal of Applied Ecology* (2022) 59: 1691; Ricart et al., 'Sinking Seaweed', 4. A lower figure is reported in DeAngelo et al., 'Economic and Biophysical', 49.

132 Arzeno-Soltero et al., 'Large Global', 7.

133 That is, 40 million square kilometres, compared to the 17 of Russia and the 85 of the Atlantic Ocean.

134 40 x 24 = 960. Pacific Ocean: 168. Earth: 501.

135 Cf. Albert Pessarrodona, Jennifer Howard, Emily Pidgeon et al., 'Carbon Removal and Climate Change Mitigation by Seaweed Farming: A State of Knowledge Review', *Science of the Total Environment* (2024) 918: 7.

136 Zi-Min Hu, Ti-Feng Shan, Jie Zhang et al., 'Kelp Aquaculture in China: A Retrospective and Future Prospects', *Reviews in Aquaculture* (2020) 13: 1324–51; Carlos M. Duarte, Annette Bruhn and Dorte Krause-Jensen, 'A Seaweed Aquaculture Imperative to Meet Global Sustainability Targets', *Nature Sustainability* (2022) 5: 185; Iona Campbell, Adrian Macleod, Christian Sahlmann et al., 'The Environmental Risks Associated with the Development of Seaweed Farming in Europe: Prioritizing Key Knowledge Gaps', *Frontiers in Marine Science* (2019) 6: 2.

137 Carlos M. Duarte, Marianne Holmer, Yngvar Olsen et al., 'Will the Ocean Help Feed Humanity?', *BioScience* (2009) 59: 967–76; Duarte et al., 'A Seaweed Aquaculture',

185–6; Pessarrodona et al., ‘Carbon Removal’, 2; DeAngelo et al., ‘Economic and Biophysical’, 46.

138 Duarte et al., ‘Seaweed Aquaculture’, 187.

139 Gao et al., ‘A Review of Existing’, 1693; Ricart et al., ‘Sinking Seaweed’, 4.

140 Cf. Thierry Chopin, Barry A. Costa-Pierce, Max Troell et al., ‘Deep-Ocean Seaweed Dumping for Carbon Sequestration: Questionable, Risky, and Not the Best Use of Valuable Biomass’, *One Earth* (2024) 7: 359–64; Ricart et al., ‘Sinking Seaweed’, 4.

141 Max Troell, Catriona Hurd, Thierry Chopin et al., ‘Seaweeds for Carbon Dioxide Removal (CDR): Getting the Science Right’, *PLOS Climate* (2024) 3: 1; Philip W. Boyd, Lennart T. Bach, Catriona L. Hurd et al., ‘Potential Negative Effects of Ocean Afforestation on Offshore Ecosystems’, *Nature Ecology and Evolution* (2022) 6: 676.

142 Jiajun Wu, David P. Keller and Andreas Oschlies, ‘Carbon Dioxide Removal via Microalgae Open-Ocean Mariculture and Sinking: An Earth System Modeling Study’, *Earth System Dynamics* (2023) 14: 185–221; Boyd et al., ‘Potential Negative’, 678.

143 Boyd et al., ‘Potential Negative’, 677, 679; and cf. Chopin et al., ‘Deep-Ocean Seaweed’, 360.

144 Andreas Oschlies, Lennart T. Bach, Katja Fennel et al., ‘Perspectives and Challenges of Marine Carbon Dioxide Removal’, *Frontiers in Climate* (2025) 6: 6; quotation from Wil Burns in Temple, ‘Companies Hoping’.

145 Ricart et al., ‘Sinking Seaweeds’, 3.

146 Lennart T. Bach, Veronica Tamsitt, Jim Gower et al., ‘Reply to: Ocean Afforestation Is a Potentially Effective Way to Remove Carbon Dioxide’, *Nature Communications* (2023) 14: 1–2; Lennart T. Bach, Veronika Tamsitt, Jim Gower et al., ‘Reply to: Rectifying Misinformation on the Climate Intervention Potential of Ocean Afforestation’, *Nature Communications* (2024) 15: 1; Boyd et al., ‘Potential Negative’, 678–9; DeAngelo et al., ‘Economic and Biophysical’, 50.

147 Manon Berger, Lester Kwiatkowski, David T. Ho and Laurent Bopp, ‘Ocean Dynamics and Biological Feedbacks Limit the Potential of Macroalgae Carbon Dioxide Removal’, *Environmental Research Letters* (2023) 18: 1–13; Lennart T. Bach, Veronica Tamsitt, Jim Gower et al., ‘Testing the Climate Intervention Potential of Ocean Afforestation Using the Great Atlantic *Sargassum* Belt’, *Nature Communications* (2021) 12: 5; Catriona L. Hurd, Cliff S. Law, Lennart T. Bach et al., ‘Forensic Carbon Accounting: Assessing the Role of Seaweeds for Carbon Sequestration’, *Journal of Phycology* (2022) 58: 357–8.

148 Boyd et al., ‘Potential Negative’, 679.

149 Ibid., 676, 679–80; Hurd et al., ‘Forensic Carbon, 358.

150 P. Boyd, J-P. Gattuso, C. L. Hurd et al., ‘Limited Understanding of Basic Ocean Processes Is Hindering Progress in Marine Carbon Dioxide Removal’, *Environmental Research Letters* (2024) 19: 2–3; Pessarrodona et al., ‘Carbon Removal’, 4–5; Chopin et al., ‘Deep-Ocean Seaweed’, 360.

151 D. A. Siegel, T. De Vries, S. C. Doney and T. Bell, ‘Assessing the Sequestration Time Scales of Some Ocean-Based Carbon Dioxide Reduction Strategies’, *Environmental Research Letters* (2021) 16: 1–9.

152 Bach et al., ‘Testing the Climate’, 4.

153 John Barry Gallagher, Victor Shelamoff and Cayne Layton, ‘Seaweed Ecosystems May Not Mitigate CO_2 Emissions’, *ICES Journal of Marine Science* (2022) 79: 585–92.

154 Pessarrodona et al., ‘Carbon Removal’, 7; Wu et al., ‘Carbon Dioxide’, 205–7; Oschlies et al., ‘Perspectives and Challenges’, 6.

155 Takemura, ‘Can We Fight’; Jackson, ‘A Look Inside’.

156 Bach et al., ‘Testing the Climate’, 4; Hurd et al., ‘Forensic Carbon’, 347–9.

157 Wu et al., ‘Carbon Dioxide’, 207; Bach et al., ‘Testing the Climate’, 4–5.
158 Hu et al., ‘Kelp Aquaculture’, 1336. See further Ik Kyo Chung, Calvyn F. A. Sondak and John Beardall, ‘The Future of Seaweed Aquaculture in a Rapidly Changing World’, *European Journal of Phycology* (2017) 52: 495–505; Duarte, ‘A Seaweed’, 185. There is, inevitably, the proposal to manage the problem by genetically modifying heat-resistant cultivars, and so the idea keeps being kicked around. See Hu et al., ‘Kelp Aquaculture’, 1340.
159 Temple, ‘Companies Hoping’.
160 DeAngelo et al., ‘Economic and Biophysical’, 51.
161 Boyd et al., ‘Potential Negative’, 675.
162 A. Oschlies, M. Pahlow, A. Yool and R. J. Matear, ‘Climate Engineering by Artificial Upwelling: Channelling the Sorcerer’s Apprentice’, *Geophysical Research Letters* (2010): 1–5. In this paper, the calculated diameter for the particular pipes was not ten but one metre, however.
163 Ibid; Oschlies et al., ‘Perspectives and Challenges’, 6. One study found that artificial upwelling would have no effect on carbon sequestration, largely because of an iron deficit at the surface; but if that method were to be combined with iron fertilisation – an idea that never dies – the result might be some drawdown: M. Jürchott, W. Koeve and A. Oschlies, ‘The Response of the Ocean Carbon Cycle to Artificial Upwelling, Ocean Iron Fertilization and the Combination of Both’, *Environmental Research Letters* (2024) 19: 1–10.
164 Nicolas Lubitz, Ryan Daly, Amy F. Smoothey et al., ‘Climate Change-Driven Cooling Can Kill Marine Megafauna at their Distributional Limits’, *Nature Climate Change* (2024), online first; National Academies of Sciences, Engineering, and Medicine, *A Research Strategy*, 245–50, 255.
165 Jan-Olaf Meynecke, Saumik Samanta, Jasper de Bie et al., ‘Do Whales Really Increase the Oceanic Removal of Atmospheric Carbon?’, *Frontiers in Marine Science* (2023) 10: 1–11; Boyd et al., ‘Limited Understanding’, 4.
166 Philip Williamson and Jean-Pierre Gattuso, ‘Carbon Removal Using Coastal Blue Carbon Ecosystems Is Uncertain and Unreliable, with Questionable Climatic Cost-Effectiveness’, *Frontiers in Climate* (2022) 4: 9.
167 Ibid., 5–9; Meynecke et al., ‘Do Whales’, 8.
168 Boyd et al., ‘Limited Understanding’, 1.
169 Interview with ocean removal expert, 17 April 2024; Alexandersson and Logadóttir, ‘Sökktu Kurli’.
170 Alexandersson and Logadóttir, ‘Sökktu Kurli’.
171 T-H. Peng and Wallace S. Broecker, ‘Dynamical Limitations on the Antarctic Iron Fertilization Strategy’, *Nature* (1991) 349: 227–29; Wallace S. Broecker, ‘Comment on “Iron Deficiency Limits Phytoplankton Growth in Antarctic Waters” by John H. Martin et al.’, *Global Biogeochemical Cycles* (1990) 4: 3–4; J. L. Sarmiento, ‘Slowing the Buildup of Fossil CO_2 in the Atmosphere by Iron Fertilization: A Comment’, *Global Biogeochemical Cycles* (1991) 5: 1–2.
172 C. Susan Weiler, ‘What Controls Phytoplankton Production in Nutrient-Rich Areas of the Open Sea?’, American Society of Limnology and Oceanography, 1991.
173 Ibid., 2–3.
174 Ibid., 6.
175 J. H. Martin, K. H. Coale, K. S. Johnson et al., ‘Testing the Iron Hypothesis in Ecosystems of the Equatorial Pacific Ocean’, *Nature* (1994) 371: 123–29.
176 Kenneth H. Coale, Kenneth S. Johnson, Steve E. Fitzwater et al., ‘A Massive Phytoplankton Bloom Induced by an Ecosystem-Scale Iron Fertilization Experiment in

the Equatorial Pacific Ocean', *Nature* (1996) 383: 495–501; Kenneth H. Coale, Kenneth S. Johnson, Francisco P. Chavez et al., 'Southern Ocean Iron Enrichment Experiment: Carbon Cycling in High- and Low-Si Waters', *Science* (2004) 304: 408–14; Philip W. Boyd, Cliff S. Law, C. S. Wong et al., 'The Decline and Fate of an Iron-Induced Subarctic Phytoplankton Bloom', *Nature* (2004) 428: 549–53; P. W. Boyd, T. Jickells, C. S. Law et al., 'Mesoscale Iron Enrichment Experiments 1993–2005: Synthesis and Future Directions', *Science* (2007) 315: 612–17; Aaron L. Strong, John J. Cullen and Sallie W. Chisholm, 'Ocean Fertilization: Science, Policy, and Commerce', *Oceonography* (2009) 22: 243; Phillip Williamson, Douglas W. R. Wallace, Cliff S. Law et al., 'Ocean Fertilization for Geoengineering: A Review of Effectiveness, Environmental Impacts and Emerging Governance', *Process Safety and Environmental Protection* (2012) 90: 475–88.

177 Hai-Bo Jiang, David A. Hutchins, Hao-Ran Zhang et al., 'Complexities of Regulating Climate by Promoting Marine Primary Production with Ocean Iron Fertilization', *Earth-Science Reviews* (2024) 249: 5. Cf. Gao et al., 'A Review of Existing', 1692.

178 Strong et al., 'Ocean Fertilization', 244.

179 Williamson et al., 'Ocean Fertilization', 479; Boyd et al., 'The Decline and Fate'.

180 See, for example, R. S. Lampitt, E. P. Achterberg, T. R. Anderson et al., 'Ocean Fertilization: A Potential Means of Geoengineering?', *Philosophical Transactions of the Royal Society A* (2008) 366: 3919–45.

181 Williamson et al., 'Ocean Fertilization', 484.

182 Strong et al., 'Ocean Fertilization', 258. Some dissenters kept calling for further research: see Smetacek and Naqvi, 'The Next Generation'; Kenneth S. Johnson and David M. Karl, 'Is Ocean Fertilization Credible and Creditable?', *Science* (2002) 296: 467–68; Ken O. Buesseler, Scott C. Doney, David M. Karl et al., 'Ocean Iron Fertilization: Moving Forward in a Sea of Uncertainty', *Science* (2008) 612: 162. But the view of the vast majority was reflected in the ranking of all proposed negative emissions technologies: ocean iron fertilisation 'is clearly the worst alternative'. Rueda et al., 'Negative-Emissions Technology', 6.

183 Strong et al., 'Ocean Fertilization', 247–250.

184 Sarmiento, as quoted in Kemi Fuentes-George, 'Consensus, Certainty, and Catastrophe: Discourse, Governance, and Ocean Iron Fertilization', *Global Environmental Politics* (2017) 17: 137.

185 Jeff Tollefson, 'Ocean-Fertilization Project off Canada Sparks Furore', *Nature* (2012) 490: 458–9; Martin Lukacs, 'World's Biggest Geoengineering Experiment "Violates" UN Rules', *Guardian*, 15 October 2012; Michael Specter, 'The First Geo-Vigilante', *New Yorker*, 18 October 2012; Kate Elizabeth Gannon and Mike Hulme, 'Geoengineering at the "Edge of the World": Exploring Perceptions of Ocean Fertilisation through the Haida Salmon Restoration Corporation', *Geo: Geography and Environment* (2018) 5: 1–21; Zach Horton, 'Going Rogue'. Ocean pasture: David Biello, 'Pacific Ocean Hacker Speaks Out', *Scientific American*, 24 October 2012.

186 With the exception that whale poo was harmless in the last regard.

187 Liam Campling and Alejandro Colás, *Capitalism and the Sea: The Maritime Factor in the Making of the Modern World* (London: Verso, 2021), 294.

188 Ibid., 268.

189 See ibid., for example, 306.

190 As recognised in passing in ibid., 295, 310.

191 Negar Vakilifard, Euripides P. Kantzas, Neil R. Edwards et al., 'The Role of Enhanced Rock Weathering Deployment with Agriculture in Limiting Future Warming and

Protecting Coral Reefs', *Environmental Research Letters* (2021) 16: 2, 4. Cf. Beerling et al., 'Potential for Large-Scale'.

192 Lennart T. Bach, Sophie J. Gill, Rosalind E. M. Rickaby et al., 'CO_2 Removal with Enhanced Weathering and Ocean Alkalinity Enhancement: Potential Risks and Co-Benefits for Marine Pelagic Ecosystems', *Frontiers in Climate* (2019) 1: 3.

193 Daniel S. Goll, Philippe Cais, Thorben Amann et al., 'Potential CO_2 Removal from Enhanced Weathering by Ecosystem Responses to Powdered Rock', *Nature Geoscience* (2021) 14: 545–9; Smith et al., 'Impacts of Land-Based', 18–19.

194 David P. Edwards, Felix Lim, Rachael H. James et al., 'Climate Change Mitigation: Potential Benefits and Pitfalls of Enhanced Rock Weathering in Tropical Agriculture', *Biological Letters* (2017) 13: 3.

195 Goll et al., 'Potential CO_2 Removal', 546.

196 Caterina Ledda, Venerando Rapisarda, Massimo Bracci et al., 'Professional Exposure to Basaltic Rock Dust: Assessment by the *Vibrio Fischeri* Ecotoxicological Test', *Journal of Occupational Medicine and Toxicology* (2013) 8: 1–5; Taylor et al., 'Enhanced Weathering', 402.

197 Thorben Amann and Jens Hartmann, 'Ideas and Perspectives: Synergies from Co-Deployment of Negative Emission Technologies', *Biogeosciences* (2019) 16: 2949–60; Sara Vicca, Daniel S. Goll, Mathilde Hagens et al., 'Is the Climate Change Mitigation Effect of Enhanced Silicate Weathering Governed by Biological Processes?', *Global Change Biology* (2022) 28: 711–26.

198 Johannes Lehmann and Angela Possinger, 'Atmospheric CO_2 Removed by Rock Weathering', *Nature* (2020): 205.

199 Mardin Abdalqadir, David Hughes, Sina Rezaei Gomari et al., 'A State of the Art of [*sic*] Review on Factors Affecting the Enhanced Weathering in Agricultural Soil: Strategies for Carbon Sequestration and Climate Mitigation', *Environmental Science and Pollution Research* (2024) 31: 19047–70.

200 Interview with enhanced weathering startup, 28 May 2024.

201 Bach et al., 'CO_2 Removal'; Edwards et al., 'Climate Change', 4. Some studies suggest a potentially negative effect on soil microbial communities: Betania Roqueto Reis, Ana Luisa Soares Vasconcelos, Antonio Marcos Miranda et al., 'Changes in Soil Bacterial Community Structure in a Short-Term Trial with Different Silicate Rock Powders', *Chemical and Biological Technologies in Agriculture* (2024) 11: 1–16.

202 Beerling et al., 'Potential for Large-Scale', 246.

203 Edwards et al., 'Climate Change', 4.

204 Renforth and Henderson, 'Assessing Ocean', 660.

205 Goll et al., 'Potential CO_2 Removal', 547.

206 Edwards et al., 'Climate Change', 5; Sovacool et al., 'Climate Protection', 8, 17.

207 Damian Carrington, 'Rock "Flour" from Greenland Can Capture Significant CO_2, Study Shows', *Guardian*, 30 May 2023. Based on the study Christiana Dietzen and Minik T. Rosing, 'Quantification of CO_2 Uptake by Enhanced Weathering of Silicate Minerals Applied to Acidic Soils', *International Journal of Greenhouse Gas Control* (2023) 125: 1–10.

208 Minik Rosing in Carrington, 'Rock "Flour"'.

209 Shuang Zhang, Christopher T. Reinhard, Shaoda Liu et al., 'A Framework for Modeling Carbon Loss from Rivers Following Terrestrial Enhanced Weathering', *Environmental Research Letters* (2025) 20: 1–9; David Roberts and Zeke Hausfather, 'What's the Deal with Enhanced Rock Weathering to Store CO_2?', *Volts*, 7 February 2025.

210 Bach et al., 'CO_2 Removal', 14. It is possible this could be good for albedo.

211 Ibid., 5; Oschlies et al., 'Climate Targets', 4; Oschlies et al., 'Perspectives and Challenges', 7–8; Daniel J. Burt, Friedrike Fröb and Tatiana Ilyina, 'The Sensitivity of Marine Carbonate System to Regional Ocean Alkalinity Enhancement', *Frontiers in Climate* (2021) 3: 1–15; Michael Fuhr, Sonja Geilert, Mark Schmidt et al., 'Kinetics of Olivine Weathering in Seawater: An Experimental Study', *Frontiers in Climate* (2022) 4: 1–20; Lennart Thomas Bach, 'The Additionality Problem of Ocean Alkalinity Enhancement', *Biogeosciences* (2024) 21: 261–77. The method would work better in summer than winter and so alkalinity might have to be added in seasonal splurges. Some latitudes are more receptive than others. Failure to abide by these conditions could mean that any soda or lime is carried away on ocean currents and into the deep, before it can work its magic. Mengyang Zhou, Michael Tyka, David Ho et al., 'Mapping the Global Variation in the Efficiency of Ocean Alkalinity Enhancement for Carbon Dioxide Removal', *Nature Climate Change* (2025) 15: 59–65.

212 Taylor et al., 'Enhanced Weathering', 403–4.

213 In the process of writing of this book, we have many times had to add or consider the latest research hot off the press. One such moment came in late 2023, when a paper in *Nature* appeared to throw the entire premise of enhanced weathering in doubt. Rocks, this paper said, also emit CO_2 when they erode and are exposed to oxygen, an effect 'rivalling or even exceeding the CO_2 drawdown by silicate weathering at the global scale'. Jesse R. Zondervan, Robert G. Hilton, Mathieu Dellinger et al., 'Rock Organic Carbon Oxidation CO_2 Release Offsets Silicate Weathering Sink', *Nature* (2023) 623: 329. Our conversation with the authors, however, revealed that this only pertained to one particular form of process whereby organic carbon locked in natural sediments is released by exposure. Since enhanced weathering does not involve the petrification of organic carbon, but only of its inorganic cousin, it appears to be unaffected by this finding. And so it marches onwards.

214 Estimates from Felix Creutzig, Christian Beyer, Jérôme Hilaire et al., 'The Mutual Dependence of Negative Emission Technologies and Energy Systems', *Energy and Environmental Science* (2019) 12: 1811. Cf. Ajay Gambhir and Massimo Tavoni, 'Direct Air Carbon Capture and Sequestration: How It Works and How It Could Contribute to Climate-Change Mitigation', *One Earth* (2019) 1: 407; and for the general point about low land demand, for example, Giulia Realmonte, Laurent Drouet, Ajay Gambhir et al., 'An Inter-Model Assessment of the Role of Direct Air Capture in Deep Mitigation Pathways', *Nature Communications* (2019) 10: 6; Jay Fuhrman, Haewon McJeon, Pralit Patel et al., 'Food-Energy-Water Implications of Negative Emissions Technologies in a +1°C Future', *Nature Climate Change* (2020) 10: 921; Jay Fuhrman, Andres Clarens, Katherine Calvin et al., 'The Role of Direct Air Capture and Negative Emissions Technologies in the Shared Socioeconomic Pathways towards +1.5°C and +2°C Futures', *Environmental Research Letters* (2021) 16: 2; Mariliis Lehtveer and Anna Emanuelsson, 'BECCS and DACCS as Negative Emission Providers in an Intermittent Electricity System: Why Levelized Cost of Carbon May Be a Misleading Measure for Policy Decisions', *Frontiers in Climate* (2021) 3: 2; Abdullatif et al., 'Emerging Trends', 5691. One study deviates from the consensus by alleging that DAC would require *more* land than BECCS, but this is based on absurdly unrealistic overestimation of the land demand for the solar power fuelling the former: June Sekera, Dominique Cagalanan, Amy Swan et al., 'Carbon Dioxide Removal: What's Worth Doing? A Biophysical and Public Need Perspective', *PLOS Climate* (2023) 2: 7–8. On

the limited land footprint of solar power (and the old tendency to overestimate it), see Malm and Carton, *Overshoot*, 174–80.

215 Repsol Foundation, 'Direct Air Capture of CO2' (Webinar), YouTube, 3 June 2020. Cf. the argument from the scholars of Climeworks in Beuttler et al., 'The Role', 4.

216 Lorenzo Rosa, Daniel L. Sanchez, Giulia Realmonte et al., 'The Water Footprint of Carbon Capture and Storage Technologies', *Renewable and Sustainable Energy Reviews* (2021) 138: 4.

217 Smith et al., 'Biophysical and Economic', 44, 47; Gambhir and Tavoni, 'Direct Air', 507.

218 Cf. Prado and Mac Dowall, 'The Cost of Permanent', 709.

219 See further the still unsurpassed Simon Hailwood, *Alienation and Nature in Environmental Philosophy* (Cambridge: Cambridge University Press, 2015).

220 Realmonte et al., 'An Inter-Model Assessment', 6.

221 Mammoth nameplate annual capacity: 36,000 tonnes – but 'the actual net removal will be lower'. Climeworks, 'Mammoth: Our Newest Facility', 2024. Using this nameplate figure, 833,333 Mammoth facilities would need to be built; given the shortfall, 1 million is a reasonable approximation.

222 Realmonte et al., 'An Inter-Model Assessment', 7. Cf. the calculations reported in June Sekera and Andreas Lichtenberger, 'Assessing Carbon Capture: Public Policy, Science, and Societal Need', *Biophysical Economics and Sustainability* (2020) 5: 17–18; Günther and Ekardt, 'Human Rights', 16.

223 Or 37 per cent: Giulia Realmonte, Laurent Drouet, Ajay Ghambir et al., 'Reply to "High Energy and Materials Requirement for Direct Air Capture Calls for Further Analysis and R&D"', *Nature Communications* (2020) 11: 1. In the worst case – so bad that it is unthinkable – manufacturing would raise energy demand by five times. Ibid.

224 Cf. for example, Sovacool et al., 'Climate Protection', 13. An almost absurdly optimistic assessment says that DAC would only need 5–10 per cent of primary energy demand to remove 40 gigatonnes per year in the latter decades of this century: Christian Breyer, Dominik Keiner, Benjamin W. Abbott et al., 'Proposing a 1°C Climate Target for a Safer Future', *PLOS Climate* (2023) 2: 3.

225 Fuhrman et al., 'The Role of Direct', 8.

226 It could even serve as a source of baseload electricity, because the biomass can, like any fossil fuel, be burned at any point. Niall Mac Dowall and Mathilde Fajardy, 'Inefficient Power Generation as an Optimal Route to Negative Emissions via BECCS?', *Environmental Research Letters* (2017) 12: 1–11.

227 Fajardy and Mac Dowall, 'The Energy Return'; Jones and Albanito, 'Can Biomass', 5360; and cf. Quiggin, 'BECCS Deployment', 5–6, 15, 18–19; Creutzig et al., 'Mutual Dependence', 1810; Turner et al., 'Unprecedented Rates', 242; Günther and Ekardt, 'Human Rights', 13.

228 On the latter, cf. Taylor et al., 'Enhanced Weathering', 406.

229 Prachi Patel, 'Move Over Direct Air Capture. Pulling CO_2 from the Ocean Could Be More Efficient', *Anthropocene Magazine*, 2023.

230 Gao et al., 'Exploration of a Novel', 226.

231 Corbin Hiar, 'Project Bison Fails: What's Next for the Carbon Removal Megaproject?', *E and E News*, 5 September 2024.

232 Allison Prang, 'Will There Be Enough Power to Remove Carbon From the Sky?', *New York Times*, 14 February 2025.

233 See for example, James Hansen, Makiko Sato, Pushker Kharecha et al., 'Young People's Burden: Requirement of Negative CO_2 Emissions', *Earth System Dynamics* (2017) 8: 591; Solone Chiquier, Mathilde Fajardy and Niall Mac Dowell, 'CO_2 Removal and

1.5°C: What, When, Where, and How?', *Energy Advances* (2022) 1: 524. Some, however, claim that seaweed would be as expensive as DAC or more: DeAngelo et al., 'Economic and Biophysical', 50–1.

234 On the general issue of the cost of DAC, see for example, Yuki Ishimoto, Masahiro Sugiyama, Etsushi Kato et al., 'Putting Costs of Direct Air Capture in Context', Forum for Climate Engineering Assessment Working Paper, June 2017, 3–4; Castro-Pardo et al., 'A Comprehensive Overview', 260. On the specific estimates mentioned here, see for example, Klaus Lackner and Habib Azarabadi, 'Buying Down the Cost of Direct Air Capture', *Industrial and Engineering Chemistry Research* (2021) 60: 8196; John Young, Noah McQueen, Charithea Charalambous et al., 'The Cost of Direct Air Capture and Storage Can Be Reduced via Strategic Deployment but Is Unlikely to Fall Below Stated Cost Targets', *One Earth* (2023) 6: 900; Abdullatif et al., 'Emerging Trends', 5691.

235 Kurt Zenz House, Antonio C. Baclig, Manya Ranjan et al., 'Economic and Energetic Analysis of Capturing CO_2 from Ambient Air', *PNAS* (2011) 108: 20428–33.

236 Jan Wurzbacher, 'Climeworks Direct Air Capture Summit 2023', YouTube, 6 June 2023.

237 The report of the cost-cutting feats of Carbon Engineering is Keith et al., 'A Process for Capturing'; Global Thermostat: Ben Soltoff, 'Inside ExxonMobil's Hookup with Carbon Removal Venture Global Thermostat', *Green Biz*, 29 August 2019; Castro-Pardo et al., 'A Comprehensive Overview', 233, 264. Cf. Jeff Tollefson, 'Price of Sucking CO_2 from Air Plunges', *Nature* (2018) 558: 173.

238 Wurzbacher, 'Climeworks'.

239 Cf. Young et al., 'The Cost of Direct', 903.

240 Wang et al., 'Reviewing Direct', 24–7, 32.

241 Lackner and Azarabadi, 'Buying Down', 8196–7, 8201–4. Cf. Fasihi et al., 'Techno-Economic Assessment', 966; Realmonte et al., 'An Inter-Model Assessment', 2; Young et al., 'The Cost of Direct', 902.

242 Creutzig et al., 'The Mutual Dependence', 1811–12, 1815.

243 Lackner and Azarabadi, 'Buying Down', 8204.

244 Pontecorvo, 'This Carbon Removal'.

245 Herzog et al., 'Getting Real'; Howard Herzog, *Carbon Capture* (Cambridge, MA: The MIT Press, 2018), 132–3; Young et al., 'The Cost of Direct', 899–900, 902, 910.

246 Cf. Lackner and Azarabadi, 'Buying Down', 8196.

247 See for example, Benjamin Lux, Niklas Schneck, Benjamin Pfluger et al., 'Potentials of Direct Air Capture and Storage in a Greenhouse Gas-Neutral European Energy System', *Energy Strategy Reviews* (2023) 45: 7–8, 13.

248 Verdox, 'Electric Carbon Removal for a Net-Zero Future', 2022.

249 Lackner and Azarabadi, 'Buying Down', 8198.

250 Young et al., 'The Cost of Direct', 903. However, the supplies of waste heat might expand in a transition from stock to flow, if centralised solar power is a major component of it: cf. Lucas Desport, Angelo Gurgel, Jennifer Morris et al., 'Deploying Direct Air Capture at Scale: How Close to Reality?', *Energy Economics* (2024) 129: 2.

251 Ibid., 904; Lackner and Azarabadi, 'Buying Down', 8198. For a pessimistic assessment of the future of DAC costs, see Herzog et al., 'Getting Real', 1478–9.

252 Christian Parenti, 'A Left Defense of Carbon Dioxide Removal: The State Must Be Forced to Deploy Civilization-Saving Technology', in J. P. Sapinski, Holly Jean Buck and Andreas Malm (eds), *Has It Come to This? The Promises and Perils of Geoengineering on the Brink* (New Brunswick: Rutgers University Press, 2021), p. 134.

253 A point made in, for example, Maria Erans, Eloy S. Sanz-Pérez, Dawid P. Hanak et al., 'Direct Air Capture: Process Technology, Techno-Economic and Socio-Political

Challenges', *Energy and Environmental Science* (2022) 15: 1389–90, 1395.

254 For example, Realmonte et al., 'An Inter-Model Assessment'; Young et al., 'The Cost of Direct'.

255 Cf. Creutzig et al., 'The Mutual Dependence', 1814; and for the need for renewables more generally, Fasihi et al., 'Techno-Economic Assessment', 966; Realmonte et al., 'Reply to "High Energy"', 2. On the use of geothermal, see also Noah McQueen, Peter Psarras, Hélène Pilorgé et al., 'Cost Analysis of Direct Air Capture and Sequestration Coupled to Low-Carbon Thermal Energy in the United States', *Environmental Science and Technology* (2020) 54: 7542–51.

256 On this tendency, see Malm and Carton, *Overshoot*, 189–218.

257 Mark Z. Jacobson, 'The Health and Climate Impacts of Carbon Capture and Direct Air Capture', *Energy and Environmental Science* (2019) 12: 3571, 3573; Mark Jacobson, *No Miracles Needed: How Today's Technology Can Save Our Climate and Clean Our Air* (Cambridge: Cambridge University Press, 2023), 117, 121, 150–1, 155–6, 186–9. The same argument is made in Sudipta Chatterjee and Kuo-Wei Huang, 'Unrealistic Energy and Materials Requirement for Direct Air Capture in Deep Mitigation Pathways', *Nature Communications* (2020) 11: 2–3; Sekera and Lichtenberger, 'Assessing Carbon Capture', 18; cf. also Sarang D. Supekar, Tae-Hwan Lin and Steven J. Skerlos, 'Costs to Achieve Target Net Emissions Reductions in the US Electric Sector Using Direct Air Capture', *Environmental Research Letters* (2019) 14: 1–11; Herzog et al., 'Getting Real', 1478. On Jacobson's work, see further Malm and Carton, *Overshoot*, for example, 171–2.

258 Dominic Boyer, 'Energopower: An Introduction', *Anthropological Quarterly* (2014) 87: 309–33.

259 Cf. Günther and Ekardt, 'Human Rights', 15–16. Note that this is slightly more specific than the study of how power in general is entwined with electricity and fuel, as in Boyer's definition of energopower: see Boyer, 'Energopower: An Introduction', 323, 325.

260 See further Malm and Carton, *Overshoot*, 210–11; and cf. Jacobson, *No Miracles*, 294–5, 298; Lehtveer and Emanuelsson, 'BECCS and DACCS', 2.

261 Jan Wohland, Dirk Witthaut and Carl-Friedrich Schleussner, 'Negative Emission Potential of Direct Air Capture Powered by Renewable Excess Electricity in Europe', *Earth's Future* (2018) 6: 1380–4; Christian Breyer, Mahdi Fasihi and Arman Aghahosseini, 'Carbon Dioxide Direct Air Capture for Effective Climate Change Mitigation Based on Renewable Electricity: A New Type of Energy System Coupling', *Mitigation and Adaptation Strategies for Global Change* (2020) 25: 46; Lehtveer and Emanuelsson, 'BECCS and DACCS', 8. A more eccentric idea, which we shall leave unremarked upon, is to attach DAC to small modular nuclear reactors: Luca Bertoni, Simon Roussanaly, Luca Riboldi et al., 'Integrating Direct Air Capture with Small Nuclear Reactors: Understanding Performance, Cost, and Potential', *Journal of Physics: Energy* (2024) 6: 1–17.

262 Interview with direct ocean capture startup, 19 June 2024.

263 Desport et al., 'Deploying Direct', 6–7, 9; Lux et al., 'Potentials of Direct Air', 9, 13; Breyer et al., 'Carbon Dioxide', 51–2; and cf. Haris Ishaq and Curran Crawford, 'Potential of Offshore Wind Energy for Direct Air Capture', *International Journal of Energy Research* (2022) 46: 18919–27.

264 One proposed alternative would be to run DAC plants on the energy from BECCS plants, which might possibly – on a very abstract plane – be extended into a utopia of vegan BECCS drawing down CO_2 both through the CCS *and* the BE powering DAC. Eric C. Okonkwo, Ahmed AlNouss, Muhammad Shahbaz and Tareq Al-Ansari,

‘Developing Integrated Direct Air Capture and Bioenergy with Carbon Capture and Storage Systems: Progress towards 2°C and 1.5°C Climate Goals’, *Energy Conservation and Management* (2023) 296: 1–16.

265 Yang Qiu, Patrick Lamers, Vassilis Daiouglu et al., ‘Environmental Trade-Offs of Direct Air Capture Technologies in Climate Change Mitigation toward 2100’, *Nature Communications* (2022) 13: 1–13; Chatterjee and Huang, ‘Unrealistic Energy’. And there is then a similar trade-off between using steel and copper and cobalt and other materials to scale up solar and wind *or* DAC, a problem foregrounded in Bisotti et al., ‘Direct Air’.

266 John Larsen, Whitney Herndon and Galen Hiltbrand, ‘Capturing New Business: The Market Opportunities Associated with Scale-Up of Direct Air Capture (DAC) Technology in the US’, *Rhodium Group*, 23 June 2020, 20.

267 Realmonte et al., ‘An Inter-Model Assessment’, 8; Günther and Ekardt, ‘Human Rights’, 17.

268 Günther and Ekardt, ‘Human Rights’, 12–13; Pessarrodona et al., ‘Carbon Removal’, 6–7; Edwards et al., ‘Climate Change’, 4; Zhou, ‘Potential CO_2’, 5–6.

269 Arun Majumdar and John Deutch, ‘Research Opportunities for CO_2 Utilization and Negative Emissions on the Gigatonne Scale’, *Joule* (2018) 2: 806, 809; Creutzig et al., ‘Mutual Dependence’, 1808; Dooley et al., ‘Carbon-Dioxide Removal’, 40; Realmonte et al., ‘An Inter-Model Assessment’, 7–8; Sekera et al., ‘Carbon Dioxide’, 8–9; Gambhir and Tavoni, ‘Direct Air’, 407; Zeeshan et al., ‘Direct Air’, 8; Sovacool et al., ‘Climate Protection’, 9.

270 Lackner and Azarabadi, ‘Buying Down’, 8199–200, 8207 (quotations from 8200). The farm capacity assumed in this equation is 1,000 tonnes per year. In other words, the estimate for total needed capacity is here one magnitude larger than that given by Realmonte et al., ‘An Inter-Model’: cf. note 214 above. The estimated price tag for these 300 million DAC farms is $45 trillion – a guess in the dark. Lackner and Azarabadi, ‘Buying Down’, 8205. On the general effect of outgassing on DAC, cf. Realmonte et al., ‘An Inter-Model Assessment’, 8; Gambhir and Tavoni, ‘Direct Air’, 408.

271 Cf. Fuhrman et al., ‘The Role of Direct’, 2.

272 For the existing practice, including CCS projects, see for example, Peter Kelemen, Sally M. Benson, Hélène Pilorgé et al., ‘An Overview of the Status and Challenges of CO_2 Storage in Minerals and Geological Formations’, *Frontiers in Climate* (2019) 1: 2, 8; Samuel Krevor, Heleen de Coninck, Sarah E. Gasda et al., ‘Subsurface Carbon Dioxide and Hydrogen Storage for a Sustainable Energy Future’, *Nature Reviews Earth and Environment* (2023) 4: 103, 105.

273 Kelemen et al., ‘An Overview’, 8–9.

274 For example, ibid., 12; Rueda et al., ‘Negative-Emissions Technology’, 4; Krevor et al., ‘Subsurface Carbon’, 102. This abundance was stressed in the very first papers on the matter: Lackner et al., ‘Carbon Dioxide Extraction’, 3–4; Möllersten and Yan, ‘Economic Evaluation’, 512–13.

275 Tim Baxter, ‘Gorgon Carbon Capture and Storage Project: The Failure of the World’s Largest CCS Facility’, *Medium*, 30 November 2024.

276 Yuting Zhang, Christopher Jackson and Samuel Krevor, ‘The Feasibility of Reaching Gigatonne Scale CO_2 Storage by Mid-Century’, *Nature Communications* (2024), 15, 6913.

277 Dan Zegart, ‘The Gassing of Satartia’, *Huffington Post*, 26 August 2021.

278 George W. Kling, Michael A. Clark, Harry R. Compton et al., ‘The 1986 Lake Nyos Gas Disaster in Cameroon, West Africa’, *Science* (1987) 236: 169–75 (quotation from 174).

279 Ibid., 173.
280 Krevor et al., ‘Subsurface Carbon’, 103. Another is shipping CO_2 on tankers.
281 Zegart, ‘The Gassing of Satartia’.
282 Nina Lakhani, ‘“Wake-Up Call”: Pipeline Leak Exposes Carbon Capture Safety Gaps, Advocates Say’, *Guardian*, 19 April 2024. The prior owner was the company Denbury.
283 Adam Willis, ‘North Dakota Wants Your Carbon, but Not Your Climate Science’, *Bloomberg*, 13 November 2024.
284 National Petroleum Council, *Meeting the Dual Challenge: A Roadmap to At-Scale Deployment of Carbon Capture, Use, and Storage*, ch. 6; Zegart, ‘The Gassing of Satartia’. Also, CO_2 pipelines need to maintain a higher pressure than gas, so there will have to be ‘more energy-gobbling compressor stations along the line to keep the CO_2 in a liquid state’, adding to the total energy demand of DAC. Zegart, ‘The Gassing of Satartia’.
285 Cindy Robertson in Lakhani, ‘Wake-Up Call’.
286 Willis, ’North Dakota’.
287 Cf. Ryan W. J. Edwards and Michael A. Celia, ‘Infrastructure to Enable Deployment of Carbon Capture, Utilization, and Storage in the United States’, *PNAS* (2018) 115: 8815–24; Maya Batres, Frances M. Wang, Holly Buck et al., ‘Environmental and Climate Justice and Technological Carbon Removal’, *The Electricity Journal* (2021) 34: 2–3; Sovacool et al., ‘Climate Privilege’, 12–16; Sekera et al., ‘Carbon Dioxide’, 13; Sekera and Lichtenberger, ‘Assessing Carbon’, 18.
288 On this attraction of abstract space, see, for example, Lackner et al., ‘Carbon Dioxide Extraction’, 11; Keith, ‘Why Capture’, 1655; Sanz-Pérez et al., ‘Direct Capture’, 11843; Castro-Pardo et al., ‘A Comprehensive Overview’, 260; Abdullatif et al., ‘Emerging Trends’, 5687; Erans et al., ‘Direct Air’, 1391.
289 M. A. Celia, S. Bachu, J. M. Nordbotten and K. W. Bandilla, ‘Status of CO_2 Storage in Deep Saline Aquifers with Emphasis on Modeling Approaches and Practical Simulations’, *Water Resources Research* (2015) 51: 6849; Krevor et al., ‘Subsurface Carbon’, 103–4.
290 For these, see Celia et al., ‘Status of CO_2’, 6847–8, 6885, 6880–1.
291 Joe Lane, Chris Greig and Andrew Garnett, ‘Uncertain Storage Prospects Create a Conundrum for Carbon Capture and Storage Ambitions’, *Nature Climate Change* (2021) 11: 928.
292 Celia et al., ‘Status of CO_2’, 6847, 6849; Kelemen et al., ‘An Overview’, 5, 8; Krevor et al., ‘Subsurface Carbon’, 104; Batres et al., ‘Environmental and Climate’, 2–3.
293 Celia et al., ‘Status of CO_2’, 6847.
294 Breyer et al., ‘Carbon Dioxide’, 61.
295 Krevor et al., ‘Subsurface Carbon’, 104; Celia et al., ‘Status of CO_2’, 6849, 6851, 6874, 6879.
296 Mark D. Zoback and Steven M. Gorelick, ‘Earthquake Triggering and Large-Scale Geologic Storage of Carbon Dioxide’, *PNAS* (2012) 109: 10164, 10167.
297 Celia et al., ‘Status of CO_2’, 6852–3, 6883; Kelemen, ‘An Overview’, 10–11; Krevor et al., ‘Subsurface Carbon’, 106.
298 Concerns about CO_2 leaks loomed large in early critical discussions of CCS but were subsequently marginalised – not because the storage of astronomic amounts of CO_2 would no longer present any problems, but because these were removed from view, owing to a familiar set of interests involved – as argued in Anders Hansson, Jonas Anshelm, Mathias Fridahl and Simon Haikola, ‘The Underworld of Tomorrow? How

Subsurface Carbon Dioxide Storage Leaked out of the Public Debate', *Energy Research and Social Science* (2022) 90: 1–6.

299 David S. Goldberg, Sara Nawaz, James Levin and Angela L. Slagle, 'Upscaling DAC Hubs with Wind Energy and CO_2 Mineral Storage: Considerations for Large-Scale Carbon Removal from the Atmosphere', *Environmental Science and Technology* (2023) 57: 21530–1.

300 Ibid., 21529–30; cf. Young et al., 'The Cost of Direct', 906. One further consideration might be that DAC devices are more efficient in capturing CO_2 in warm and humid regions – back to the tropics, in other words. Keju An, Azharuddin Farooqui and Sean T. McCay, 'The Impact of Climate on Solvent-Based Direct Air Capture Systems', *Applied Energy* (2022) 325: 1–11.

301 Colin D. Hills, Nimisha Tripathi and Paula J. Carey, 'Mineralization Technology for Carbon Capture, Utilization, and Storage', *Frontiers in Energy Research* (2020) 8: 2.

302 Juerg M. Matter, Martin Stute, Sandra Ó. Snæbjörnsdottir et al., 'Rapid Carbon Mineralization for Permanent Disposal of Anthropogenic Carbon Dioxide Emissions', *Science* (2016) 352: 1312.

303 Ibid., 1313.

304 Damien Daval, 'Carbon Dioxide Sequestration through Silicate Degradation and Carbon Mineralisation: Promises and Uncertainties', *NPJ Materials Degradation* (2018) 2: 3.

305 Kelemen et al., 'An Overview', 1, 14.

306 Ibid., 2.

307 HJS, 'Inject, Baby, Inject!', *Science* (2016) 352: 1288. Cf. Josh Gabbatiss, '"Drill, Baby, Drill": The Surprising History of Donald Trump's Fossil-Fuel Slogan', *Carbon Brief*, 18 March 2024.

308 Rosalia Trias, Bénédicte Ménez, Paul le Campion et al., 'High Reactivity of Deep Biota under Anthropogenic CO_2 Injection into Basalt', *Nature Communications* (2017) 8: 1–14; and cf. Daval, 'Carbon Dioxide'.

309 Daval, 'Carbon Dioxide', 3.

310 Cf. Niall Mac Dowell, Paul S. Fennell, Nilay Shah and Geoffrey C. Maitland, 'The Role of CO_2 Capture and Utilization in Mitigating Climate Change', *Nature Climate Change* (2017) 7: 244–5; Kelemen et al., 'An Overview, 11–12; Fuhrman et al., 'Food-Energy-Water Implications', 921–3.

311 See further Lane et al., 'Uncertain Storage'.

312 Engels, *Dialectics of Nature*, 180, 183.

313 Matthew Brander, Francisco Ascui, Vivian Scott and Simon Tett, 'Carbon Accounting for Negative Emissions Technologies', *Climate Policy* (2021) 21: 699–717. Cf. Powis et al., 'Quantifying Global', 2.

314 Cf. S. Julio Friedmann, 'Engineered CO_2 Removal, Climate Restoration, and Humility', *Frontiers in Climate* (2019) 1: 2; Supekar et al., 'Costs to Achieve'.

315 This paradox is implicit in the entire literature on negative emissions technologies. See for example, Klaus S. Lackner, Sarah Brennan, Jürg M. Matter et al., 'The Urgency of the Development of CO_2 Capture from Ambient Air', *PNAS* (2012) 109: 13161; Hansen et al., 'Target Atmospheric', 14; Hansen et al., 'Young People's', 591, 595–6; Anderson et al., 'Natural Climate', 934; Powis et al., 'Quantifying Global', 7–9; Deprez et al., 'Sustainability Limits', 486.

316 Masson-Delmotte et al., 'Summary for Policymakers', 18 (emphasis added).

10. Of Sewage Ideologues and Other Savants

1 Of course, there is also the possibility of *continuing with less* and cancelling it out: a scenario associated with the notion of 'residual emissions'. We shall deal with this further below. Here the focus is on the general continuation of fossil fuel combustion. Likewise, there is the possibility of *continuing with ever-larger emissions*, the 40 gigatonnes of the early 2020s becoming 45, 50 … this, indeed, would be business as usual.

2 Marx, *Capital. Volume I*, 284.

3 See for example, Nils Markusson, Duncan McLaren and David Tyfield, 'Towards a Cultural Political Economy of Mitigation Deterrence by Negative Emissions Technologies (NETs)', *Global Sustainability* (2018) 1: 1–9; Duncan McLaren and Nils Markusson, 'The Co-Evolution of Technological Promises, Modelling, Policies and Climate Change Targets', *Nature Climate Change* (2020) 10: 392–7; Nils Markusson, Duncan McLaren, Bronislaw Szerszynski et al., 'Life in the Hole: Practices and Emotions in the Cultural Political Economy of Mitigation Deterrence', *European Journal of Futures Research* (2022) 10: 1–14; Wim Carton, Inge-Merete Hougaard, Nils Markusson and Jens Friis Lund, 'Is Carbon Removal Delaying Emission Reductions?', *WIREs Climate Change* (2023) 14: 1–18.

4 Dyson, 'Can We Control', 288. Cf. Nathalie Berta and Alain Roux, 'The Endless Expansion of Carbon Offsetting: Sequestration by Agricultural Soils in Historical Perspective', *Cambridge Journal of Economics* (2024), online first, 5. 'Johnny Appleseed and the Greenhouse' likewise operated on the assumption that afforestation would correspond to emissions in quantity: Booth, 'Johnny Appleseed'.

5 Freeman Dyson and Gregg Marland, 'Technical Fixes for the Climatic Effects of CO_2', in William P. Elliott and Lester Machta (eds), *Workshop on the Global Effects of Carbon Dioxide from Fossil Fuels, Miami Beach, Fla., March 7–11, 1977*, US Department of Energy, 111–18; Roger A. Sedjo, 'Forests: A Tool to Moderate Global Warming?', *Environment: Science and Policy for Sustainabile Development* (1989) 31: 15; Marland, 'The Prospect of Solving', 2.

6 Marland, 'The Prospect of Solving', 1; and cf. Paul Schroeder and Lew Ladd, 'Slowing the Increase of Atmospheric Carbon Dioxide: A Biological Approach', *Climatic Change* 19 (1991): 283–90.

7 Nebojsa Nakicenovic and John Aviott, 'CO_2 Reduction and Removal: Measures for the Next Century', *Energy* (1991) 16: 1372. The institute: International Institute for Applied Systems Analysis, later an IAM hub.

8 Ibid., 1375.

9 Volker A. Mohnen, Walter Goldstein and Chyung Wang, 'The Conflict over Global Warming: The Application of Scientific Research to Policy Choices', *Global Environmental Change* (1991) 1: 111, 118.

10 Martin, 'Iron, Liebig's', 55.

11 As quoted in Caroline Dopyera, 'The Iron Hypothesis', *Earth Magazine*, October 1996, 30.

12 Peter G. Brewer, 'Roger Revelle Commemorative Lecture Contemplating Action: Storing Carbon Dioxide in the Ocean', *Oceanography* (2000) 13: 91. Cf. Booth, 'Johnny Appleseed', 20; Booth, 'Ironing Out'.

13 As for BECCS, see Malm and Carton, *Overshoot*, 63.
14 Seifritz, 'CO_2 Disposal', 486.
15 Walter Seifritz, *Sanfte Energietechnologie: Hoffnung Oder Utopie?* (München: Verlag Karl Thiemig, 1980).
16 Walter Seifritz, 'Technical Communication: Optimum CO_2 Management of the Atmosphere', *International Journal of Hydrogen Energy* (1995) 20: 504; and cf. Walter Seifritz, *Der Treibhauseffekt: Technische Maßnahmen Zur CO_2-Entsorgung* (München, Wien: Carl Hanser Verlag, 1991), 152.
17 Walter Seifritz, 'The Terrestrial Storage of CO_2-Dry Ice', *Energy Conversion and Management* (1993) 34: 1121; Walter Seifritz, 'Mirrors to Halt Global Warming?' *Nature* 340 (1989): 603. The latter quotation pertains to solar geoengineering, of which Seifritz was also an early advocate; see further below.
18 Seifritz, 'The Terrestrial Storage', 1124.
19 Bruno Fritsch, Stephan Schmidheiny and Walter Seifritz, *Towards an Ecologically Sustainable Growth Society: Physical Foundations, Economic Transitions, and Political Constraints* (Berlin: Springer, 1994), 122, 126.
20 Nordhaus, 'Can We', 39, 8 (emphasis added). On Nordhaus as the first to promote removal, cf. Berta and Roux, 'The Endless Expansion', 5; on this and his other work, Malm and Carton, *Overshoot*, 57–9, 74–6, 80, 86, 93.
21 Nordhaus, 'Can We', 46; on the special cheapness of the deep ocean, see 42–4.
22 William D Nordhaus, 'Economic Approaches to Greenhouse Warming', in Rudiger Dornbush and James M. Poterba (eds), *Global Warming: Economic Policy Approaches* (Cambridge, MA: MIT Press, 1991), 51–2.
23 Lackner et al., 'Carbon Dioxide Extraction', 1153; see further 1154, 1164, 1168.
24 Klaus Lackner, Darryl P. Butt, Christopher H. Wendt et al., 'Carbon Dioxide Disposal in Mineral Form: Keeping Coal Competitive', Los Alamos National Laboratory, November 1997, 1 (emphasis added). On this as a figure for the US alone, see the report to the Department of Energy: Klaus S. Lackner, Darryl P. Butt and Christopher H. Wendt, 'Binding Carbon Dioxide in Mineral Form: A Critical Step towards a Zero-Emission Coal Power Plant', Los Alamos National Laboratory/DOE Office of Scientific and Technical Information, November 1998, 2. As for the pandering, cf. the following language: 'Future constraints on CO_2 emissions could become much more draconian if a clear connection can be made between ecological or economic damages and increased atmospheric CO_2 levels. If such a connection exists, the ability to demonstrate its existence is growing rapidly. Thus, one can expect that such a connection will be found if it is there.' Ibid., 5. Such agnosticism about anthropogenic global warming was here integrated into the concern for investments: *if* it turns out to be real, we can expect an attack on the capital involved.
25 Ibid., 6. The same charges against renewables were made in Lackner et al., 'Binding Carbon', 2.
26 Lackner et al., 'Binding Carbon', 1 (emphasis added). The almost identical formulation is in Lackner et al., 'Carbon Dioxide Disposal in Mineral', i.
27 Lackner et al., 'Binding Carbon', 1. Cf. 7; Lackner et al., 'Carbon Dioxide Disposal in Mineral', i, 1. On other occasions, however, Lackner slid back to the second configuration and the notion of buying time. When he unveiled his first DAC contraption at Columbia, he said: 'I have long believed science and industry have the technological capability to design systems that will capture greenhouse gases and allow us to transition to energies of the future over the long term.' Columbia Climate School, 'First Successful'. But even here, the optimism about DAC was paired with pessimism

about renewables: ‘Experts have long highlighted the potential of air extraction, arguing that it could have a vastly greater impact than the renewable energy sources that currently operate on a small scale.’ Ibid. At other points again, Lackner alleged that DAC would ‘assure plentiful, low-cost [i.e. fossil] energy for the century, giving better alternatives ample time to mature’. Lackner, ‘A Guide’, 1678. Cf. Lackner et al., ‘Binding Carbon’, 2.

28 ‘From the point of view of the fossil fuel industry, the only useful solution to the problem is one that keeps access to fossil fuels available’: and this was the point of view expressly adopted in Lackner et al., ‘Carbon Dioxide Disposal in Mineral’, 10. Or: ‘fossil fuels are in an excellent position to stay competitive except for the issue of severe limits on carbon dioxide emissions. Such limits are likely to be imposed. An industry that has a technical solution to the problem is obviously in a much stronger position to cope with the problem’. Ibid., 6.

29 Lackner et al., ‘Carbon Dioxide Disposal in Mineral’; as for this second report, the Los Alamos National Laboratory denied us access to it.

30 Lackner et al., ‘Carbon Dioxide Extraction’ (more precisely, the 24th Annual Technical Conference on Coal Utilization and Fuel Systems, in Clearwater, Florida).

31 Ibid., 1–2. Sometimes the expected concentration issuing in from coal alone was a slightly more modest 3,500 ppm: Lackner et al., ‘Carbon Dioxide Disposal in Carbonate’, 1168.

32 Lackner et al., ‘Carbon Dioxide Extraction’, 1–2, 4.

33 Klaus S. Lackner, ‘A Guide to CO_2 Sequestration’, *Science* (2003) 300: 1678.

34 Klaus S. Lackner, ‘Washing Carbon Out of the Air’, *Scientific American* (2010) 71; cf. 66.

35 Ibid., 66; cf. 69.

36 Lackner et al., ‘The Urgency of the Development’, 13156.

37 Klaus S. Lackner, Richard Wilson and Hans-Joachim Ziock, ‘Free-Market Approaches to Controlling Carbon Dioxide Emissions to the Atmosphere: A Discussion of the Scientific Basis’, in Behram N. Kurşunoğlu, Stephan L. Mintz and Arnold Perlmutter (eds), *Global Warming and Energy Policy* (New York: Springer, 2001), 2, 3.

38 Lackner et al., ‘Carbon Dioxide Extraction’, 2; Lackner et al., ‘The Urgency of the Development’, 13160–1. The same potential was attributed to enhanced weathering in Lackner et al., ‘Carbon Dioxide Disposal in Carbonate’, 1164.

39 Klaus S. Lackner and Christophe Jospe, ‘Climate Change Is a Waste Management Problem’, *Issues in Science and Technology* (2017) 33: 83–88.

40 Cesare Marchetti, ‘On Geoengineering and the CO_2 Problem’, *Climatic Change* (1977) 1: 59–68; and cf. C. Marchetti, ‘Constructive Solutions to the CO_2 Problem’, *Developments in Atmospheric Science* (1979) 10: 299–311.

41 Lackner and Jospe, ‘Climate Change, 84.

42 On class disparities in emissions, see Malm and Carton, *Overshoot*, 223–7.

43 Lackner and Jospe, ‘Climate Change’, 84, 87. Lackner’s arguments were entirely coloured by this system-maintaining purpose: DAC must be thermodynamically viable, because ‘otherwise there would be a very big advantage to eliminating all carbonaceous fuels from the transportation sector’. Lackner, ‘The Thermodynamics of Direct’, 44.

44 Lackner and Jospe, ‘Climate Change’, 88.

45 Keith in McKendrick, *Scrubbing*, 70. This work drips with admiration for Lackner’s genius and influence: see for example, 26, 29, 114.

46 Huber, ‘Could Seaweed’.

47 S. Elliot, K. S. Lackner, H. J. Ziock et al., ‘Compensation of Atmospheric CO_2 Buildup through Engineered Chemical Sinkage’, *Geophysical Research Letters* (2001) 28: 1235–6, 1238.

48 Robert Kunzig and Wallace S. Broecker, *Fixing Climate: The Story of Climate Science – and How to Stop Global Warming* (London: Profile, 2009), 15. On the ideas developed out of the collaboration between Broecker and Lackner, see 230–59; on their deeds in Iceland, 254–6.

49 Ibid., 218–20, 226 (quotation from 220).

50 Ibid., 229.

51 Wally Broecker, ‘Does Air Capture Constitute a Viable Backstop against a Bad CO_2 Trip?’, *Elementa: Science of the Anthropocene* (2013) 1: 3.

52 Kunzig and Broecker, *Fixing Climate*, 268.

53 The National Academies of Sciences, Engineering, and Medicine, *Carbon Management: Implications for R & D in the Chemical Sciences and Technology* (Washington, DC: National Academy Press, 2001), 216.

54 E. A. Parson and D. W. Keith, ‘Fossil Fuels without CO_2 Emissions’, *Science* (1998) 282: 1054.

55 David Keith, ‘Industrial Carbon Management’, in The National Academies of Sciences, Engineering, and Medicine, *Carbon Management*, 129. See also David W. Keith and Edward A Parson, ‘A Breakthrough in Climate Change Policy?’, *Scientific American* (2000) 282: 78–9; Timothy L. Johnson and David W. Keith, ‘Electricity from Fossil Fuels without CO_2 Emissions: Assessing the Costs of Carbon Dioxide Capture and Sequestration in US Electricity Markets’, *Journal of the Air and Waste Management Association* (2001) 51: 1452–9.

56 Aimee E. Curtright, M. Graner Morgan and David Keith, ‘Expert Assessments of Future Photovoltaic Technologies’, *Environmental Science and Technology* (2008) 42: 9031–8.

57 Joseph F. Decoralis and David W. Keith, ‘The Real Cost of Wind Energy’, *Science* (2001) 294: 1000; Amanda S. Adams and David W. Keith, ‘Are Global Wind Power Resource Estimates Overstated?’, *Environmental Research Letters* (2013) 8: 1–9; and cf. Lee M. Miller and David W. Keith, ‘Observation-Based Solar and Wind Power Capacity Factors and Power Densities’, *Environmental Research Letters* (2018) 12: 1–11.

58 To be exact, he wrote: ‘If US electricity demand was met with US-based wind power, the wind farm array would need to operate for more than a century before the warming effect over the Continental US caused by turbine-atmosphere interactions would be smaller than the reduced warming effect from lowering emissions.’ Lee M. Miller and David W. Keith, ‘Climatic Impacts of Wind Power’, *Joule* (2018) 2: 2629. See also David W. Keith, Joseph F. DeCarolis, David C. Denkenberger et al., ‘The Influence of Large-Scale Wind Power on Global Climate’, *PNAS* (2004) 101: 16115–20.

59 See for example, Keith, ‘Why Capture’, 1655; David Keith in TVO Today, ‘Climate IV: What to Do? Geoengineering!’, YouTube, 18 March 2010.

60 David W. Keith, Minh Ha-Duong and Joshuah K. Stolaroff, ‘Climate Strategy with CO_2 Capture from the Air’, *Climatic Change* (2006) 74: 17.

61 Ibid., 17, 33 (emphasis added).

62 Chichilnisky and Bal, *Reversing Climate*, 58; cf. for example, Graciela Chichilnisky and Peter Eisenberger, ‘Energy Security, Economic Development and Global Warming: Addressing Short and Long Term Consequences’, *International Journal of Green Economics* (2009) 3: 419. Lackner also made the token acknowledgement that emissions would have to be cut at some point, returning to the second configuration: see for example, Lackner et al., ‘The Urgency of the Development’, 13160.

63 Chichilnisky and Bal, *Reversing Climate*, 58, 56 (emphasis added); cf. 255. This book is largely an advocacy for 'green capitalism': see for example, 202, 235–47. It was endorsed by none other than Lord Nicholas Stern.
64 Chichilnisky and Eisenberger, 'Energy Security', 426.
65 Ibid., 418–19; Peter M. Eisenberger, Roger W. Cohen, Graciela Chichilnisky et al., 'Global Warming and Carbon-Negative Technology: Prospects for a Lower-Cost Route to a Lower-Risk Atmosphere', *Energy and Environment* (2009) 20: 976. The second author of this article, Mr. Cohen, was a 'climate sceptic', explicitly identified as such in Peter M. Eisenberger, 'Chaos Control: Climate Stabilization by Closing the Global Carbon Cycle', *Energy and Environment* (2014) 25: 989.
66 Chichilnisky and Bal, *Reversing Climate*, 59 (emphases added).
67 Eisenberger, 'Chaos Control', 971, 985–6.
68 Ibid., 974–5.
69 Paul Nahi in Calma, 'Why This New'.
70 Interview, 20 February 2020; second quotation from Beuttler et al., 'The Role', 5.
71 Castro-Pardo et al., 'A Comprehensive Overview', 227–8. One version of this argument was that population growth inevitably causes a growth in fossil fuel consumption, for which DAC must cover: Sanz-Pérez et al., 'Direct Capture', 11840, 11842.
72 Desport et al., 'Deploying Direct', 3–4. Similar arguments applied, of course, to other negative emissions technologies as well: in the oceans, they would help 'extend the period of time in that fossil fuels can be extracted in reasonable amounts'. Ignoring them would be to commit the sin of ignoring 'optimisation potential' in climate politics. Wilfried Rickels and Thomas S. Lontzek, 'Optimal Global Carbon Management with Ocean Sequestration', *Oxford Economic Papers* (2012) 64: 324, 345.
73 Realmonte et al., 'An Inter-Model Assessment', 3. See also the similar results in Ayami Hayashi, Fuminori Sano, Takashi Homma and Keigo Akimoto, 'Mitigating Trade-Offs Between Global Food Access and Net-Zero Emissions: The Potential Contribution of Direct Air Carbon Capture and Storage', *Climatic Change* (2023) 176: 1–19.
74 Fuhrman et al., 'Food-Energy-Water Implications', 921. Cf. Rebecca Draeger, Bruno S. L. Cunha, Eduardo Müller-Casseres et al., 'Stranded Crude Oil Resources and Just Transition: Why Do Crude Oil Quality Climate Ambitions and Land-Use Emissions Matter', *Energy* (2022) 255: 1–13.
75 Shreekar Pradhan, William M. Shobe, Jay Fuhrman et al., 'Effects of Direct Air Capture Technology Availability on Stranded Assets and Committed Emissions in the Power Sector', *Frontiers in Climate* (2021) 3: 3 (cf. for example, 10).
76 Candelaria Bergero, Matthew Binsted, Osama Younis et al., 'Technology, Technology, Technology: An Integrated Assessment of Deep Decarbonization Pathways for Canadian Oil Sands', *Energy Strategy Reviews* (2022) 41: 1–13; Yang Qiu, Gokul Iyer, Jay Furhman et al., 'The Role and Deployment Timing of Direct Air Capture in Saudi Arabia's Net-Zero Transition', *Environmental Research Letters* (2024) 19: 1–10.
77 Adam Dorr, 'The Impact and Restoration Curves: Going beyond Mitigation and Stabilization', *Anthropocene* (2016) 16: 64.

11. We Are Going to Be Forever Driven by Value

1 Kevin Crowley and David Wethe, 'Exxon Ramps Up Carbon Capture in Deal with Top US Steelmaker', *Bloomberg*, 1 June 2023.

2 Corbin Hiar, ‘Exxon CEO Says Carbon Removal Is Climate Cure with Oil Perks’, *E and E News*, 28 June 2022.
3 ‘ExxonMobil (XOM) Q4 2023 Earnings Call Transcript’, *Motley Fool*, 2 February 2024.
4 Amanda Drane, ‘Exxon Announces Climate Solution Pilot Project during CERA Week Conference in Houston’, *Houston Chronicle*, 18 March 2024; Spencer Kimball, ‘Exxon Is Working on Tech to Remove CO_2 from Atmosphere but a Breakthrough Is Needed to Slash Cost’, *CNBC*, 26 April 2024; Corbin Hier, ‘Oil Companies Want to Remove Carbon from the Air – Using Taxpayer Dollars’, *E and E News*, 13 July 2023; Nia Williams, ‘Exxon Working on Direct Air Capture of CO_2, Stays Out of EV Charging Stations’, *Reuters*, 19 September 2023; and see further Darren Woods in ‘ExxonMobil (XOM) Q4 2023’.
5 ExxonMobil, ‘Direct Air Capture’, 2023–24.
6 ExxonMobil, ‘Advancing Climate Solutions: Progress Report, 2023’, 45; cf. 61.
7 Darren Woods in ‘ExxonMobil (XOM) Q4 2023’.
8 ExxonMobil, ‘Plants’, YouTube, 18 March 2019; and see further Cartie Werthman, ‘Despite Advertising Carbon Capture, ExxonMobil Saw Marginal Role for It in Fighting Climate Change’, *DeSmog*, 21 May 2024.
9 On the algae programme and its fate, see Malm and Carton, *Overshoot*, 209–10.
10 Eisenberger in ExxonMobil, ‘ExxonMobil Expands Agreement with Global Thermostat, Sees Promise in Direct Air Capture Technology’, 21 September 2020; Chichilnisky in McKendrick, *Scrubbing*, 47. On the partnership, see further, for example, ExxonMobil, ‘ExxonMobil and Global Thermostat to Advance Breakthrough Atmospheric Carbon Capture Technology’, 27 June 2019; Bel Soltoff, ‘Inside ExxonMobil’s Hookup with Carbon Removal Venture Global Thermostat’, *Green Biz*, 29 August 2019; McKendrick, *Scrubbing*, 46–7, 53–4, 58–9. Cf.: ‘He [Eisenberger] doesn’t have an unkind word to say about his former employer Exxon, and he’s quick to point out that fossil fuels were key in advancing human society to where it is today.’ Siegel, ‘The Fizzy Math’.
11 Kaufman and Rathi, ‘A Carbon-Sucking’.
12 Dimana Doneva, ‘Exxon to Advance Direct Air Capture With Its Own Pilot Project’, *Carbon Herald*, 3 July 2023; cf. ExxonMobil, ‘Advancing Climate’, 65, 82.
13 ExxonMobil, ‘Advancing Climate’, 65, 82; ExxonMobil, ‘Caring for Land and Biodiversity’, 8 January 2024.
14 Gregory Trencher, Mathieu Blondeel and Jusen Asuka, ‘Do All Roads Lead to Paris? Comparing Pathways to Net-Zero by BP, Shell, Chevron and ExxonMobil’, *Climatic Change* (2023) 1176: 13.
15 On this year and its significance, see Malm and Carton, *Overshoot*, for example, 10–20.
16 Matt DiLallo, ‘ExxonMobil Is Becoming a Moneymaking Machine’, *Motley Fool*, 7 February 2024. Profits fell from $55.7 billion in 2022 to $36 billion in 2023, the latter thereby being the second biggest profit since 2012: Myles McKormick, ‘ExxonMobil and Chevron Notch Second-Biggest Annual Profits in Decade’, *Financial Times*, 2 February 2024.
17 Russel Searancke, ‘ExxonMobil Unveils Ambitions for Earnings and Production Growth’, *Upstream*, 12 December 2023.
18 Oliver Milman, ‘Surge of New US-Led Oil and Gas Activity Threatens to Wreck Paris Climate Goals’, *Guardian*, 28 March 2024.
19 Darren Woods in ‘ExxonMobil (XOM) Q4 2023’.
20 Julie Hyman, ‘ExxonMobil Chief Woods Calls for “Consistency” in US Climate Policy’, *Yahoo! Finance*, 19 March 2024.
21 For example: ‘Frankly, we’re at the very early stages of the technology and the technology development. So, whether we’re successful or somebody else is successful, I

feel like this is an area worth exploring. And I think our technology companies have got some great ideas.' Darren Woods in 'ExxonMobil (XOM) Q4 2023'. See further Woods in Natashya Angelica, 'Earnings Call: ExxonMobil Reports Robust Q1 Earnings, Plans Growth', *Investing*, 29 April 2024; Avi Salzman, 'Exxon Makes a Long-Shot Bet on Climate Tech. Sizing Up the Costs', *Barron's*, 30 April 2024.

22 Quoted in Juliette Wood, 'The Search for the Holy Grail: Scholars, Critics and Occultists', *Proceedings of the Harvard Celtic Colloquium* (2002) 22: 226.

23 Ibid., 233.

24 Ibid., 229, 237.

25 Carbon Engineering, 'Investment from Oxy Low Carbon Ventures and Chevron Technology Ventures', 9 January 2019; Virginia Furness, 'Chevron Leads $318 Mln Raise for Carbon Capture Tech Firm Svante', *Reuters*, 15 December 2022.

26 Chevron, 'Climate Change Resilience: Advancing a Lower Carbon Future', 2021, 52. For the project, see Clean Energy Systems, 'BECCS Project', 2024.

27 Chevron, 'Climate Change', 53.

28 International Emissions Trading Association and Carbon Market Institute, 'Markets for Natural Climate Solutions: An NCS Options Paper for Australia October 2020', 3.

29 Chevron, 'Chevron and Restore the Earth Foundation Agree to Collaborate on Carbon Offsets Restoration Project in Louisiana', 28 March 2022.

30 Chevron, 'Fact Sheet: Gorgon Carbon Capture and Storage', 2022. The company also supported soil carbon sequestration in Australia. 'Chevron to Finance Carbon Sequestration Projects in WA', *Petroleum Australia*, 18 August 2023.

31 Victoria R. Clark and Howard J. Herzog, 'Can "Stranded" Fossil Fuel Reserves Drive CCS Deployment?', *Energy Procedia* (2014) 7261–71.

32 Graham Readfearn, 'Gas Giant Chevron Falls Further Behind on Carbon Capture Targets for Gorgon Gasfield', *Guardian*, 15 July 2022; Adam Morton, 'Emissions from WA Gas Project with World's Largest Industrial Carbon Capture System Rise by More than 50%', *Guardian*, 20 April 2023.

33 Stephen Stapczynski, 'Big Oil's Climate Fix Is Running Out of Time to Prove Itself', *Bloomberg*, 13 September 2023.

34 Chevron, 'Update to Climate Change Resilience: A Framework for Decision Making', February 2019, 9; McKormick, 'ExxonMobil and Chevron'.

35 Trencher et al., 'Do All Roads', 13.

36 Antonio Hicks, 'Avnos Inc. Secures Funding and Strategic Partnerships from ConocoPillips, JetBlue Ventures and Shell Ventures, Totaling Over $80M', *Business Wire*, 13 July 2023.

37 Center for Negative Carbon Emissions, 'Shell's New Energy and Research Technology (NERT) Group – Materials and Shapes for Advanced Filters Removing CO_2 from Wind', Arizona State University, 2018.

38 Mathis, 'Big Oil'. On Shell's interest in DAC, see also for example, *Politico*, 'The Future of Carbon Removals: Setting the Right Standards', 22 February 2023.

39 Seddon et al., 'Getting the Message', 1523, 1529; Select Carbon, 'Shell to Acquire Environmental Services Company Select Carbon', August 2020; and for Shell's kink, see further Buller, *The Value*, 78–9, 86.

40 TotalEnergies, 'Sustainability and Climate 2022 Progress Report', 2, 38; see further this report and Total, 'Getting to Net Zero', September 2020; TotalEnergies, 'Carbon Capture and Storage, a Solution to Reduce Our Emissions and Those of Our Customers', 2 June 2023; Theodora Stankova, 'TotalEnergies and Partners to Test Subsea CO_2 Capture Technology in Brazil', *Carbon Herald*, 11 January 2024. Earlier, however, Total did put some money in a lesser-known DAC startup called Cambridge

Quantum Computing: Total, ‘Total is Exploring Quantum Algorithms to Improve CO_2 Capture’, 14 May 2020.

41 These scenarios often stayed within the second configuration: ‘The time it takes for parts of the energy sector to transition away from fossil fuels highlights the likely importance of carbon dioxide removal (CDR) in helping to reduce net carbon emissions during the transition period while these reforms are undertaken, as well as offsetting any remaining gross emissions in a net zero energy system.’ BP, ‘Energy Outlook 2023’, 15; cf. 77–9.

42 Repsol News, ‘NET: Negative Emissions Technologies’, 2024; Repsol, ‘Capturing and Reusing CO_2: A New Alternative to Fight Climate Change’, 2024; Violet George, ‘Repsol Sinopec Announces First Direct Air Capture Project in Brazil’, *Carbon Herald*, 9 December 2022.

43 Captura, ‘Captura Raises US$21.5M, with Investments from Maersk Growth, Eni Next and EDP’, 22 January 2024 (i.e. Direct Ocean Capture.)

44 Captura, ‘Equinor and Captura Partner to Develop Ocean Carbon Removal’, 11 January 2023; Captura, ‘Equinor Leads’; OGJ Editors, ‘Equinor, Captura Partner to Develop Ocean Carbon Removal Pilot Project’, *Oil and Gas Journal*, 1 November, 2023.

45 Government of Norway, ‘Questions and Answers about the Longship Project’, 13 October 2021; CCD Norway, ‘The Longship CCS Project’, 2022; Northern Lights, ‘About the Longship Project’, n.d.; Equinor, ‘Could a Pipeline from Europe to Norway Help Solve European Industry’s Climate Problem?’, 2024.

46 Mathis, ‘Big Oil’; Sintef, ‘Capturing Carbon with Sugar Kelp’, 2022; Carbon Kapture, ‘What We Do’, 2023.

47 Theodora Stankova, ‘Aker BP Announces Kelp Carbon Removal Project in Norway’, *Carbon Herald*, 17 January 2024; Lundin Energy, ‘Fuelling the Energy Transition: Sustainability Report 2021’, 18. Lundin Energy merged with Aker BP. On the history of the former company, see Malm and Carton, *Overshoot*, 128–30.

48 *Reuters*, ‘Lundin Sells First “Carbon Neutral” Oil as Climate Activism Grows’, 26 April 2021; Bojan Lepic, ‘Lundin Sells First Carbon-Neutral Oil from Johan Sverdrup’, 16 June 2021.

49 Hussein K. Abdel-Aal, *Economic Analysis of Oil and Gas Engineering Operations* (Boca Raton: CRC Press, 2021), 179.

50 For details on the technology, see Shadfar Davoodi, Mohammed Al-Shargabi, David A. Wood et al., ‘Carbon Dioxide Sequestration through Enhanced Oil Recovery: A Review of Storage Mechanisms and Technological Applications’, *Fuel* (2024) 366: 1–32. For the history, see Global Energy Monitor, ‘CO_2 Enhanced Oil Recovery’, 19 July 2021.

51 Davoodi et al., ‘Carbon Dioxide, 2.

52 Mengwei Zhao, ‘The Impact of CO_2-Enhanced Oil Recovery on Oil Production and Lifespan of Old Oil Pools: A Canadian Example’, *AAPG Bulletin* (2024) 108: 215–23.

53 Russel Gold, ‘Why Peak-Oil Predictions Haven’t Come True’, *Wall Street Journal*, 28 September 2014.

54 US Energy Information Administration, *Annual Energy Outlook 2010: With Projections to 2035* (Washington: National Energy Information Center, 2010), 75. The share of production animated by enhanced oil recovery stood at somewhere between 2 and 3 per cent in the 2010s: see, for example, Global Energy Monitor, ‘CO_2 Enhanced’.

55 Kinder Morgan advertisement in *Odessa American*, 14 September 2003.

56 Vello Kuuskraa and Matt Wallace, ‘CO_2-EOR Set for Growth as New CO_2 Supplies Emerge’, *Oil and Gas Journal* (2014) 112: 92–4.

57 See for example, Pamela Tomski, ‘The Business Case for Carbon Capture, Utilization and Storage’, Atlantic Council Issue Brief, 2012.

58 Seven largest by revenue: Ty Haqqi, ‘15 Biggest Oil Companies in USA’, *Yahoo! Finance*, 13 June 2021. On the roaring profits of Occidental, see, for example, *Reuters*, ‘Occidental Beats Profit Estimates on Higher Oil Prices’, 7 May 2024.

59 Thom Allen and Mike Coffin, ‘Paris Maligned: Why Investors Should Assess the Climate Alignment of Oil and Gas Companies’, *Carbon Tracker*, December 2022, 27, 30. Among the world’s fifty top public companies producing oil and gas, Oxy had the seventh highest emissions intensity (Scope 1 to 3, i.e. in production as well as products). Simon Dietz, Dan Gardiner, Valentin Jahn and Jolien Noels, ‘How Ambitious Are Oil and Gas Companies’ Climate Goals?’, *Science* (2021) 374: 406.

60 Akshat Rathi, ‘Construction Begins on the World’s Largest Carbon Removal Plant’, *Bloomberg*, 27 October 2022. Cf. Natasha White, Akshat Rathi and Kevin Crowley, ‘An Oil Giant Quietly Ditched the World’s Biggest Carbon Capture Plant’, *Bloomberg*, 23 October 2023.

61 Akshat Rathi, ‘A Tiny Tweak in California Law Is Creating a Strange Thing: Carbon-Negative Oil’, *Quartz*, 1 July 2019.

62 Testimony of Richard Jackson, president, Low Carbon Ventures, Occidental Petroleum, Committee on Energy and Natural Resources, 16 May 2019. ‘Ultimately, we think we can be carbon negative.’ Hollub in Clifford Krauss, ‘Blamed for Climate Change, Oil Companies Invest in Removal’, *New York Times*, 7 April 2019.

63 Hollub in Carolyn Davis, ‘Oxy Taking “Contrarian Approach” to Net-Zero Emissions by Developing Oil Resources, Reusing CO_2’, *Natural Gas Intelligence*, 13 November 2020.

64 Hollub in Ben Lefebvre, ‘Oil Industry Sees a Vibe Shift on Climate Tech’, *Politico*, 8 March 2023.

65 Hollub in Daniel Estrin and Camila Domonoske, ‘Sucking Carbon Dioxide Out of the Sky Is Moving from Science Fiction to Reality’, NPR, 8 September 2023.

66 Erik Kobayashi-Solomon, ‘Carbon Engineering’s Licenses to Print Money’, *Forbes*, 9 October 2020.

67 *Economist*, ‘Can Carbon Removal Become a Trillion-Dollar Business? Quite Possibly – And Not Before Time’, 21 May 2023.

68 Paul Ehrlich, ‘Notrees, Texas: A Small Town with a Strange Name’, *Authentic Texan*, 2021.

69 Oxy, ‘Occidental and BlackRock Form Joint Venture to Develop STRATOS, the World’s Largest Direct Air Capture Plant’, 2023.

70 Rathi, ‘Construction Begins’; ‘What Is Direct Air Capture?’, 1PointFive, 2024. On the beginning of the project, see further for example, Oliver Milman, ‘The World’s Biggest Carbon Capture Facility Is Being Built in Texas. Will It Work?’, *New York Times*, 12 September 2023; Camila Domonoske, ‘This Oil Company Invests in Pulling CO_2 Out of the Sky – So It Can Keep Selling Crude’, *KERA News*, 27 December 2023.

71 As noted in David Gelles, ‘Can We Engineer Our Way Out of the Climate Crisis?’, *New York Times*, 31 March 2024.

72 ‘1PointFive Holds Groundbreaking for World’s Largest Direct Air Capture (DAC) Plant’, 1PointFive, 2023.

73 Camille Bond, ‘Occidental Eyes Massive CO_2 Removal Project’, *EnergyWire*, 11 April, 2022; Carbon Engineering, ‘1PointFive and Carbon Engineering Announce Direct Air Capture Deployment Approach to Enable Global Build-Out of Plants’, *Global News Wire*, 7 June 2022.

74 Oxy, ‘Occidental and BlackRock Form Joint Venture to Develop STRATOS, the World’s Largest Direct Air Capture Plant’, 7 November 2023; Trent Jacobs, ‘Oxy Attracts World’s Largest Investment House to World’s Largest DAC Project’, *Journal of Petroleum Technology*, 8 November 2023.

75 McKendrick, *Scrubbing*, 74.

76 Temple, ‘Startups Looking’.

77 Interview with Steve Oldham, 27 August 2020.

78 ‘Written Testimony of Steve Oldham CEO, Carbon Engineering, before the Senate Environment and Public Works Committee, February 27, 2019’, Carbon Engineering, 2, 4.

79 Erik Kobayashi-Solomon, ‘Capitalism vs Climate Change: Front Line Interview’, *Forbes*, 21 May 2019.

80 Kevin Crowley, ‘Occidental to Buy Canadian Startup Carbon Engineering for $1.1 Billion’, *Bloomberg*, 15 August 2023.

81 Paulina Jaramillo, W. Michael Griffin and Sean T. McCoy, ‘Life Cycle Inventory of CO_2 in an Enhanced Oil Recovery System’, *Environmental Science and Technology* (2009) 43: 8027; Sekera and Lichtenberger, ‘Assessing Carbon’, 13–14.

82 Sekera and Lichtenberger, ‘Assessing Carbon’, 6–7; and see further for example, R. Farajzadeh, A. A. Eftekhari, G. Dafnomilis et al., ‘On the Sustainability of CO_2 Storage through CO_2 – Enhanced Oil Recovery’, *Applied Energy* (2020) 261: 1–12; Barnaby Pace and Lindsay Fendt, ‘Direct Air Capture: Big Oil’s Latest Smokescreen’, *Center for International Environmental Law*, November 2023, 1, 4.

83 Jaramillo and McCoy, ‘Life Cycle’; and cf. Sekera and Lichtenberger, ‘Assessing Carbon’, 13. This figure is irrespective of the source of CO_2.

84 Pace and Fendt, ‘Direct Air’, 4.

85 See for example, Sekera and Lichtenberger, ‘Assessing Carbon’, 11; Castro-Pardo et al., ‘A Comprehensive Overview’, 233.

86 Consoli, ‘2019 Perspective’, 5. These were therefore BECCS plants coupled to enhanced oil recovery.

87 Taylor Noakes, ‘Sell Our CO_2 to Pump More Oil? It’s Likely, Says Iowa-Based Carbon Capture Project’, *DeSmog*, 8 April 2024.

88 Justine Kalma, ‘To Capture CO_2 in the US, Climate Tech Startups Partner with Oil and Gas’, *The Verge*, 21 April 2023; Brian Kahn, ‘A Startup Battles Big Oil for the $1 Trillion Future of Carbon Cleanup’, *Bloomberg*, 19 October 2023. On California Resources Corporation, see, for example, Howard Fine, ‘CRC Forms Joint Ventures to Sequester Carbon at Well Sites’, *Los Angeles Business Journal*, 29 August 2022; Alejandro Lazo, ‘Vital Climate Tool or License to Pollute? The Battle Over California’s First Carbon Capture Project’, *KPBS*, 17 April 2024; ‘Where We Operate’, California Resources Corporation, 2024. At this point, Climeworks still insisted that the CO_2 it planned to capture on American soil would not go to enhanced oil recovery. The partnership with California Resources Corporation suggested that this last taboo might soon crumble as well.

89 Pace and Fendt, ‘Direct Air’, 7.

90 See for example, Tobias Zumbraegel, *Political Power and Environmental Sustainability in the Gulf Monarchies* (Singapore: Palgrave Macmillan, 2022), 241–3; ADNOC, ‘ADNOC to Expand Use of EOR and ERD Technologies to Maximise Value of Resources’, ADNOC, 10 November 2016; Aarti Nagraj, ‘Adnoc Awards $227m Contract for Enhanced Recovery at Bab Oilfield’, *The National News*, 7 March 2022.

91 Mikaila Adams, ‘Occidental, ADNOC to Fund UAE Direct Air Capture Project Study’, 3 October 2023; ADNOC, ‘ADNOC and Occidental to Advance Direct Air Capture Project in the UAE’, 3 October 2023.

92 AFP, ‘Climate Math “Doesn’t Add Up” without Carbon Capture: COP28 Chief’, *France 24*, 5 October 2023. In a common move at this point in time, the reference here was to ‘carbon capture’ technologies broadly defined, for oil and gas majors spanning a spectrum from fossil CCS to DAC.

93 Maha El Dahan, ‘UAE’s Jaber Says Oil, Industrial Firms to Commit to Decarbonization at COP28’, *Reuters*, 2 October 2023.

94 Shihab Alfaheem in Sayumi Take, ‘COP28 Host UAE Says Fossil Fuels Needed in Energy Transition: Envoy’, *Nikkei Asia*, 5 September, 2023.

95 Lackner et al., ‘Carbon Dioxide Extraction’, 3

96 P. B. Kelemen, R. Aines, E. Bennett et al., ‘*In Situ* Carbon Mineralization in Ultramafic Rocks: Natural Processes and Possible Engineered Methods’, *Energy Procedia* (2018) 146: 92–102; Henry Fountain, ‘How Oman’s Rocks Could Help Save the Planet’, *New York Times*, 26 April 2018.

97 ‘44.01 Signs Agreement with Oman’s Ministry of Energy and Minerals for a First of Its Kind Carbon Removal Project’, 44.01, 2023

98 ‘44.01 Commences Injection at UAE’s First Mineralisation Project’, 44.01, 2023; Anthony Di Paola, ‘UAE Starts Sucking Carbon from Air to Convert It into Rock’, *Bloomberg*, 21 November 2023; Dimana Doneva, ‘44.01 and ADNOC Begin Carbon Mineralization Project in the UAE’, *Carbon Herald*, 22 November 2023. Quotation from the earlier announcement, ‘ADNOC Partners with 44.01 to Turn CO_2 into Rock’, ADNOC, 17 January 2023. The emirate: Fujairah.

99 Statements from ADNOC in Damian Carrington, ‘Revealed: UAE Plans Huge Oil and Gas Expansion as It Hosts UN Climate Summit’, *Guardian*, 4 April 2023.

100 Cf. Matthew Taylor, ‘Capturing Cop28 Chief’s Oil Firm Emissions Would Take Centuries – Study’, *Guardian*, 15 November 2023.

101 Abdul Sattar Al-Taie, ‘QF’s Research Fund Awards Grants to Projects Designed to Drive Qatar’s Socioeconomic Development’, *Albawaba*, 19 July 2020. Qatari researchers made the case for air-conditioning DAC in Ahmed Sodiq, Yasser Abdullatif, Brahim Aissa et al., ‘A Review on Progress Made in Direct Air Capture of CO_2’, *Environmental Technology and Innovation* (2023) 29: 1–24. The case began with an acceptance of the fact that fossil fuels are here to stay: ibid., 1.

102 Aramco, ‘2 Million Mangroves Added to the Carbon Front Line’, 2024.

103 ClientEarth, ‘Greenwashing Files: Aramco’, 2024. Annual figures.

104 *Reuters*, ‘Saudi Arabia Commits $2.5 Bln to Middle East Green Initiative – Crown Prince’, 7 November 2022; Kingdom of Saudi Arabia, ‘Middle East Green Initiative’, Vision 2030, 2024.

105 Sebastien Malo, ‘Do “Mechanical Trees” Offer the Cure for Climate Change?’, *Saudi Gazette*, 1 May 2019; ‘Climate Change: New Ideas for Sucking Up CO_2 from Air Shows Promise’, *Saudi Gazette*, 9 March 2023; Li et al., ‘Critical Review’, 899; Aramco Asia Korea, ‘Mobile Carbon Capture’, 2023. Aramco reported capture rates of between 20 and 40 per cent of the emitted CO_2.

106 John Fialka, ‘Mining the Sky for CO_2 with Metal Trees, Towers and Pumps’, *E and E News*, 5 January 2021; Captura, ‘Equinor Leads’; CarbonCapture, ‘Direct Air Capture Company CarbonCapture Inc. Closes $80 Million Series A Financing’, *PR Newswire*, 12 March 2024; Spiritus, ‘Aramco and Spiritus to Advance Direct Air Capture Technology, Investment by Aramco Ventures’, *Carbon Capture Magazine*, 22 May

2024; Aramco, ‘Aramco Advances Development of Emissions Reduction Solutions’, 9 October 2023; Felicia Bradstock, ‘Saudi Arabia’s Ambitious Decarbonization Plans’, *OilPrice*, 16 October 2023. The list also included Ucaneo (slogan: ‘We Build the Lung for the Planet’): Nirmal Narayanan, ‘Aramco Ventures Invests in Ucaneo to Develop Germany’s Largest Direct Air Capture Plant’, *Arab News*, 11 March 2025.

107 Marianna Parraga and Arathy Somasekhar, ‘Big Oil Executives Push Back against Calls for Fast Energy Transition’, *Reuters*, 18 March 2024.

108 Oliver Milman, ‘Executives at Texas Summit Claim Clean-Energy Transition Is Failing and Say World Should “Abandon the Fantasy” of Fossil-Fuel Phaseout’, *Guardian*, 20 March 2024.

109 Arathy Somasekhar and Maha El Dahan, ‘More Chance of Elvis Speaking than Energy Transition Plans Succeeding, Aramco CEO Says’, *Reuters*, 10 March 2025.

110 See for example, Jon Gambrell, ‘Oil Giant Saudi Aramco Makes a Historic $161B Profit in 2022’, *AP*, 4 March 2023.

111 Tom Wilson and Ahmed Al Omran, ‘Saudi Aramco Increases Dividend to Nearly $100bn Despite Oil Price Falls’, *Financial Times*, 10 March 2024; Jon Gambrell, ‘Aramco Announces $121 Billion Profit in 2023, Saudi Oil Giant’s 2nd Highest on Record’, *PBS*, 10 March 2024.

112 Damian Carrington, ‘Revealed: Saudi Arabia’s Grand Plan to “Hook” Poor Countries on Oil’, *Guardian*, 27 November 2023.

113 Corbin Hiar, ‘Oil Companies Want to Remove Carbon from the Air – Using Taxpayer Dollars’, *E and E News*, 13 July 2023.

114 For example, Jessica Green, Jennifer Hadden, Thomas Hale and Paasha Mahdavi, ‘Transition, Hedge, or Resist? Understanding Political and Economic Behavior toward Decarbonization in the Oil and Gas Industry’, *Review of International Political Economy* (2022) 29: 2036–63; Trencher et al., ‘Do All Roads Lead to Paris?’ Gregory Trencher, ‘Keeping Your Fossil-Fuel Cake while Eating It? Comparing the Decarbonization Approach of BP, Chevron, ExxonMobil and Shell’, in Yukio Adachi and Makoto Usami (eds), *Governance for a Sustainable Future: The State of the Art in Japan* (Singapore: Springer, 2023), 251–78; Dietz et al., ‘How Ambitious’. 0.1 per cent: Green et al., ‘Transition, Hedge’, 2051.

115 Green et al., ‘Transition, Hedge’, 2038.

116 Ibid., 2037–9; and see further Malm and Carton, *Overshoot*, for example, 164–5.

117 Here following Natalie Koch, ‘Sustainability Spectacle and “Post-Oil” Greening Initiatives’, *Environmental Politics* (2023) 32: 711, 726.

118 The literature on the former is vast; for some basic data, see Malm and the Zetkin Collective, *White Skin*, 13, 18–21, 25–32; for the latter, see, for example, Joanna Depledge, ‘Striving for No: Saudi Arabia and the Climate Change Regime’, *Global Environmental Politics* (2008) 8: 9–35.

119 Quotation from George Ferns, Kenneth Amaeshi and Aliette Lambert, ‘Drilling Their Own Graves: How the European Oil and Gas Supermajors Avoid Sustainability Tensions through Mythmaking’, *Journal of Business Ethics* (2019) 158: 208; see further, for example, 207; Ensieh Shojaeddini, Stephen Naimoli, Sarah Ladislaw and Morgan Bazilian, ‘Oil and Gas Company Strategies Regarding the Energy Transition’, *Progress in Energy* (2019) 1: 7.

120 Cf. Ferns et al., ‘Drilling Their Own’, 201–4.

121 Adorno, ‘Reflections on Class Theory’, in *Can One Live after Auschwitz? A Philosophical Reader* (Stanford: Stanford University Press, 2003 [1942]), 94.

122 Equinor, ‘Exploration for Oil and Gas’, 2024.

123 Cf. for example, Sarah Benabou, Nils Moussu and Birgit Müller, ‘The Business Voice at COP21: The Quandaries of a Global Political Ambition’, in Stefan C. Aykut, Jean Foyer and Edouard Morena (eds), *Globalising the Climate: COP21 and the Climatisation of Global Debates* (Abingdon: Routledge, 2017), 63; Robert J. Brulle, Melissa Aronczyk and Jason Carmichael, ‘Corporate Promotion and Climate Change: An Analysis of Key Variables Affecting Advertising Spending by Major Oil Corporations, 1986–2015’, *Climatic Change* (2020) 159: 88; Janina Herzog-Hawelka and Joyeeta Gupta, ‘The Role of (Multi)national Oil and Gas Companies in Leaving Fossil Fuels Underground: A Systematic Literature Review’, *Energy Research and Social Science* (2023) 103: 6.

124 Koch, ‘Sustainability Spectacle’, 715 (here quoting Michael F. Brown); Ferns et al., ‘Drilling Their Own’, 203. For the theatrical aspect, see Malm and Overshoot, 89.

125 See for example, Mei Li, Gregory Trencher and Jusen Asuka, ‘The Clean Energy Claims of BP, Chevron, ExxonMobil and Shell: A Mismatch between Discourse, Actions and Investments’, *PLoS One* (2022) 17: 1–27; Green et al., ‘Transition, Hedge’, 2037–8.

126 Steve Kennedy of Amegy Bank in Jeffrey Rothfeder and Christopher Maag, ‘How Wall Street’s Fossil-Fuel Money Pipeline Undermines the Fight to Save the Planet’, *Fortune*, 23 February 2023.

127 Green et al., ‘Transition, Hedge’, 2037, 2052, 2058.

128 On the first factor, see Stefan C. Aykut, Edouard Morena and Jean Foyer, ‘“Incantatory” Governance: Global Climate Politics’ Performative Turn and Its Wider Significance for Global Politics’, *International Politics* (2021) 58: 20–6, 31; and further, Malm and Carton, *Overshoot*, for example, 38–9.

129 Cf. for example, Atif Ansar, Ben Caldecott and James Tilbury, ‘Stranded Assets and the Fossil Fuel Divestment Campaign: What Does Divestment Mean for the Valuation of Fossil Fuel Assets?’, Stranded Asset Programme (Smith School of Enterprise and the Environment, and University of Oxford), October 2013, 65; Herzog-Hawelka and Gupta, ‘The Role of (Multi)national’, 8; and further Malm and Carton, *Overshoot*, for example, 102–5.

130 Chevron, ‘Climate Change’, 11.

131 Cf. Julie Ayling and Neil Gunningham, ‘Non-State Governance and Climate Policy: The Fossil Fuel Divestment Movement’, *Climate Policy*, 136; Herzog-Hawelka and Gupta, ‘The Role of (Multi)national’, 7.

132 In the convoluted words of Fiona Wild, vice president for sustainability and climate change at BHP: ‘This [investing in DAC in general and Carbon Engineering in particular] is about recognising that climate change poses significant risks to all economic sectors. Climate change is no longer seen as a fringe issue. It’s a business risk that requires a business response.’ Krauss, ‘Blamed for Climate’. Or as Lackner himself puts it: ‘Oil companies’ entire business model will fall apart if carbon dioxide cannot be recovered from the atmosphere and environmental carbon constraints become more severe.’ Lackner and Jospe, ‘Climate Change’, 87.

133 Green et al., ‘Transition, Hedge’, 2037, 2043–4. Or, ‘future-proofing’ the oil and gas companies: Nathalie Koch, ‘Greening Oil Money: The Geopolitics of Energy Finance Going Green’, *Energy Research and Social Science* (2022) 93: 8. Koch demonstrates how the UAE has been future-proofing its heavily fossilised economy by engaging in some spectacular projects in renewables and conservation on the side; the same logic applies to removal.

134 Lackner et al., ‘Binding Carbon’, 2.

135 *Economist*, ‘Can Carbon’.

136 David Keith, ‘David Keith on Why Carbon Removal Won’t Save Big Oil but May Help the Climate’, *Economist*, 28 September 2023. In the wake of this op-ed, Keith was even

reported to have said that DAC is ‘over-hyped’. Pace and Fendt, ‘Direct Air’, 8.

137 Cf. Sara Nawaz, Duncan McLaren, Holly Caggiano et al., ‘Agenda for a Progressive Political Economy of Carbon Removal’, Institute for Responsible Carbon Removal, American University, February 2024, 11, 15, 17–18; Emily Grubert and Shuchi Talati, ‘The Distortionary Effects of Unconstrained For-Profit Carbon Dioxide Removal and the Need for Early Governance Intervention’, *Carbon Management* (2024) 15: 1–2, 9–10.

138 Jason P. Dinh, ‘The Hijack and Reclamation of Direct Air Capture’, *Atmos*, 5 December 2023.

139 Emily Pontecorvo, ‘Biden’s Risky Bet That Oil Companies Can Lead a New Climate Industry’, *Heatmap*, 14 September, 2023. Granholm also believed in time travelling, as we have seen.

140 Jean Renée, ‘Biden’s Energy Secretary Affirms There Is a Future for the Oil and Gas Industry in a Low-Carbon World’, *Williston Herald*, 14 May 2021.

141 Kevin Crowley, ‘How an Oil Giant Took Control of Biden’s Billion-Dollar Bet on Carbon Capture’, *Bloomberg*, 28 August 2023.

142 Ibid.; James Temple, ‘The US Just Invested More Than $1 Billion in Carbon Removal’, *MIT Technology Review*, 11 August 2023; Joe Lo, ‘US Sparks Controversy by Backing Oil Company’s Carbon-Sucking Plans’, *Climate Home News*, 15 August 2023.

143 Seher Dareen, ‘Occidental’s 1PointFive Secures Funding of up to $500 Mln from US DOE’, *Reuters*, 13 September 2024.

144 For the use of this instrument to support renewable energy projects, see Sarah Knuth, ‘Rentiers of the Low-Carbon Economy? Renewable Energy’s Extractive Fiscal Geographies’, *EPA: Economy and Space* (2023) 55: 1548–64.

145 Petya Trendafilova, ‘What is the 45Q Tax Credit?’, *Carbon Herald*, 8 November 2023. Cf. Pace and Fendt, ‘Direct Air’, 11–12; Nawaz et al., ‘Agenda for a Progressive’, 19, 23. The amount per tonne sequestered through DAC without enhanced oil recovery or any other utilisation was $180 – but this was still a hypothetical activity on US soil as of 2024, at which point it still only existed in Iceland.

146 Office of Fossil Energy and Carbon Management, ‘About Us’, n.d. (emphasis added). Cf. James Temple, ‘The US Agency in Charge of Developing Fossil Fuels Has a New Job: Cleaning Them Up’, *MIT Technology Review*, 2 September 2022.

147 Office of Fossil Energy and Carbon Management, ‘Why We Celebrate Carbon Management Day’, 28 November 2023.

148 US Energy Information Administration, ‘United States Produces More Crude Oil than Any Country, Ever’, 11 March 2024; Myles McCormick and Jamie Smyth, ‘US Oil Production Forecast to Reach New Heights Despite Drilling Slowdown’, *Financial Times*, 9 January 2024.

149 Myles McCormick, ‘US Places $1.2bn Climate Bet on Tech Pulling Carbon from Air’, *Financial Times*, 11 August 2023.

150 Cf. Nawaz et al., ‘Agenda for a Progressive’, 6–7; Grubert Talati, ‘The Distortionary Effects’, 4.

151 Katie Brigham, ‘Trump Hollowed Out the Government’s Carbon Removal Team’, *Heatmap*, 28 February 2025.

152 Oxy, transcript of Q4 2024 Occidental Petroleum Corp Earnings Call, 19 February 2025, 16.

153 Robert Steward, ‘Occidental Foresees Donald Trump Support of US Direct Air Capture Plans’, *Upstream*, 14 November 2024.

154 Willis, ‘North Dakota’

155 Ibid.

156 Robert Stavins, ‘Project 88 – Harnessing Market Forces to Protect Our Environment: Initiatives for the New President. A Public Policy Study Sponsored by Senator Timothy E. Wirth, Colorado, and Senator John Heinz, Pennsylvania’ (Washington, DC: Environmental Policy Institute, 1988), 2. Apart from Stavins, who lead the effort, the author list included prominent theorists of emissions trading such as Robert Hahn and Tom Tietenberg.

157 Ibid., 1–3.

158 For general histories and critiques of neoliberal environmental economics, see, for example, Troy Vettese, ‘Limits and Cornucopianism: A History of Neo-Liberal Environmental Thought, 1920–2007’, PhD dissertation, New York University; David Pearce, ‘An Intellectual History of Environmental Economics’, *Annual Review of Energy and the Environment* (2002) 27: 57–81; Philip Mirowski, *Never Let a Serious Crisis Go to Waste: How Neoliberalism Survived the Financial Meltdown* (London: Verso, 2014), 334–42. For overviews of the early history of emissions trading specifically, see Richard Lane, ‘The Promiscuous History of Market Efficiency: The Development of Early Emissions Trading Systems’, *Environmental Politics* (2012) 21: 583–603; Larry Lohmann, ‘Toward a Different Debate in Environmental Accounting: The Cases of Carbon and Cost–Benefit’, *Accounting, Organizations and Society* (2009) 34: 499–534; Larry Lohmann, ‘Neoliberalism and the Calculable World: The Rise of Carbon Trading’, in Kean Birch, Vlad Mykhnenko and Katherine Trebeck (eds), *The Rise and Fall of Neoliberalism: The Collapse of an Economic Order?* (London: Zed Books, 2010), 77–93. A more recent critique of carbon markets is Buller, *The Value*, 57–98.

159 Robert Stavins, ‘Project 88’, 17, 20. GHG = Greenhouse Gas Emissions.

160 Ibid., 20. This story is also narrated in Berta and Roux, ‘The Endless Expansion’.

161 Philip Schabecoff, ‘US Utility Planting 52 Million Trees’, *New York Times*, 12 October 1988.

162 Sheryl D. Sturges, ‘Greenhouse Gas Emission Offsets: A Global Warming Insurance Policy’, *The Electricity Journal* (1993) 6: 71.

163 Ibid.

164 Schabecoff, ‘US Utility’.

165 Pedro Moura-Costa and Marc D. Stuart, ‘Forestry-Based Greenhouse Gas Mitigation: A Story of Market Evolution’, *The Commonwealth Forestry Review* (1998) 77: 193; Mark C. Trexler, ‘Carbon Offset Strategies: A Private Sector Perspective’, in Catrinus J. Jepma (ed.), *The Feasibility of Joint Implementation* (Dordrecht: Springer Netherlands, 1995), 237.

166 Schabecoff, ‘US Utility’; Lohmann, ‘The Dyson Effect’, 51; Chris Lang, ‘How a Forestry Offset Project in Guatemala Allowed Emissions in the USA to Increase’, *REDD-Monitor*, 9 October 2009.

167 Moura-Costa and Stuart, ‘Forestry-Based Greenhouse’, 193. ‘The objective’, in the words of Face itself, ‘is to create the absorbing capacity for a 600 MW modem coal-fired powerplant’. See Hans Verweij, ‘Forests Absorbing Carbon Dioxide Emission’, in Jepma, *The Feasibility*, 331.

168 Those three countries would provide 125,000 hectares; 20,000 would come from the Czech Republic; the remaining 5,000 from the Dutch homeland.

169 Trexler, ‘Carbon Offset’, 236. The sources somewhat conflict on the amount of land and carbon involved; on some accounts, AES did remain the largest in terms of volume. For a comprehensive overview of early offsetting projects, see Moura-Costa and Stuart, ‘Forestry-Based Greenhouse’, 194.

170 Berta and Roux, ‘The Endless Expansion’, 7.

171 Moura-Costa and Stuart, ‘Forestry-Based Greenhouse Gas Mitigation’, 195.
172 Fred Pearce, ‘All Gas and Guesswork: Nations Trying to Agree Practical Steps to Combat Global Warming Are Finding that They Do Not Have the Crucial Figures’, *New Scientist*, 30 July 1994.
173 Lohmann, ‘The Dyson Effect’, 2.
174 UNFCCC, ‘UNFCCC Ad Hoc Group on the Berlin Mandate: Eighth Session, Second Part Kyoto, 30 November 1997, Agenda Item 3. Response from Parties on Issues Related to Sinks’, 52; Martina Jung, ‘The History of Sinks: An Analysis of Negotiating Positions in the Climate Regime’, Hamburg Institute of International Economics, Discussion Paper No. 293, 2004, 3–4; Cathleen Fogel, ‘Biotic Carbon Sequestration and the Kyoto Protocol: The Construction of Global Knowledge by the Intergovernmental Panel on Climate Change’, *International Environmental Agreements: Politics, Law and Economics* (2005) 5: 194; Eva Lövbrand, ‘Revisiting the Politics of Expertise in Light of the Kyoto Negotiations on Land Use Change and Forestry’, *Forest Policy and Economics* (2009) 11: 407. ‘There is no way we will agree’, this coalition said of the Kyoto Protocol, ‘unless we can credit some land use activities’. As quoted in Kate Dooley and Aarti Gupta, ‘Governing by Expertise: The Contested Politics of (Accounting for) Land-Based Mitigation in a New Climate Agreement’, *International Environmental Agreements: Politics, Law and Economics* (2017) 17: 487.
175 Berta and Roux, ‘The Endless Expansion’; Moura-Costa and Stuart, ‘Forestry-Based Greenhouse Gas Mitigation’; Ian Fry, ‘Twists and Turns in the Jungle: Exploring the Evolution of Land Use, Land-Use Change and Forestry Decisions within the Kyoto Protocol’, *Review of European Community and International Environmental Law* 11 (2002): 159–68.
176 See note 189 on page 496 above.
177 Emily Boyd, Esteve Corbera and Manuel Estrada, ‘UNFCCC Negotiations (Pre-Kyoto to COP-9): What the Process Says about the Politics of CDM-Sinks’, *International Environmental Agreements: Politics, Law and Economics* (2008) 8: 99.
178 As quoted in Lövbrand, ‘Revisiting the Politics’, 407.
179 The seminal document from this period was Larry Lohmann, ‘Carbon Trading: A Critical Conversation on Climate Change, Privatisation and Power’, *Development Dialogue* (2006) 36: 5–362. The history offered in this section is brief and also incomplete: during these years and indeed decades, a jungle of technicalities and complications and objections and counter-objections grew up around offsetting, itself expanding in all directions like an ever more impenetrable bush of weed. Here we merely draw out the broad lines of the period. For more detailed accounts, see, for example, ibid.
180 ‘Cheat Neutral’, YouTube, 22 July 2007.
181 IISD Earth Negotiations Bulletin, ‘Bolivia Climate Change Project Finalized’, 11 March 1998. The two utilities: American Electrical Power and PacifiCorp.
182 Moura-Costa and Stuart, ‘Forestry-Based Greenhouse’, 199.
183 Dooley and Aarti Gupta, ‘Governing by Expertise’, 495 (emphasis in original).
184 United Nations Framework Convention on Climate Change (UNFCCC), ‘Paris Agreement’, 2015, 4 (article 4.1).
185 In conformity with the laws explored by Ellen Meiksins Wood and generations of other Marxists.
186 On the limited public funding for removals, see for instance Rhodium Group, ‘The Landscape of Carbon Dioxide Removal and US Policies to Scale Solutions’, 10 April 2024.

187 CDR.fyi, ‘Keep Calm and Remove On – CDR.fyi 2024 Year in Review’, 14 February 2025.

188 John Vidal, ‘How Bill Gates Aims to Clean up the Planet’, *Guardian*, 4 February 2018.

189 Bill Gates, *How to Avoid a Climate Disaster: The Solutions We Have and the Breakthroughs We Need* (London, Great Britain: Allen Lane, 2021), 19. In the same breath, he would mouth that ‘carbon removal is not an excuse to keep emitting’. Michelle Ma, ‘A Bill Gates–Backed Startup Just Launched that Could Remove 5,000 Tons of Carbon Dioxide from the Atmosphere by Year End’, *Fortune*, 13 December 2023.

190 Heather Clancy, ‘Inside Microsoft’s Record-Breaking Carbon Removal Contract’, *GreenBiz*, 22 May 2024.

191 Ørsted, ‘Ørsted Awarded Contract – Will Capture and Store 430,000 Tonnes of Biogenic CO_2’, 15 May 2023. On Ørsted, cf. Malm and Carton, *Overshoot*, 214, 235.

192 1PointFive, ‘Microsoft Agrees to Purchase 500,000 Tonnes of DAC Carbon Removal Credits’, 9 July 2024. The terms of this deal specified that this quantum of removal could not thereby be used for enhanced oil recovery.

193 Microsoft, ‘How Can We Advance Sustainability? 2024 Environmental Sustainability Report’, 20.

194 1PointFive, ‘Microsoft agrees’.

195 Microsoft, ‘How Can’; Lucas Joppa, Amy Luers, Elizabeth Willmott et al., ‘Microsoft’s Million-Tonne CO_2-Removal Purchase: Lessons for Net Zero’, *Nature* (2021) 597: 629; Microsoft, ‘Microsoft Carbon Removal: Lessons from an Early Corporate Purchase’, 2021, 13, 16–17, 21; Mark Segal, ‘Microsoft Signs Another Reforestation-Based Carbon Removal Megadeal’, *ESG Today*, 13 May 2024.

196 Brad Smith, ‘Microsoft Will Be Carbon Negative by 2030’, Official Microsoft Blog, 16 January 2020. Cf. Joppa et al., ‘Microsoft’s Million-Tonne’, 629–30; Microsoft, ‘Microsoft Carbon’, 8.

197 For example, Aine Fox, ‘Microsoft Pledges to Remove Entire Historical Carbon Footprint by 2050’, *Yahoo! Finance*, 16 January 2020; Justine Calma, ‘Microsoft Wants to Capture All of the Carbon Dioxide It’s Ever Emitted’, *The Verge*, 16 January 2020; David Roberts, ‘Microsoft’s Astonishing Climate Change Goals, Explained’, *Vox*, 30 July 2020.

198 Alison Murphy, ‘Who Has Directed Sustainability and Social Impact Work at Companies Like Lime and Lululemon’, in Roberts, ‘Microsoft’s Astonishing’.

199 Smith, ‘Microsoft Will’.

200 Microsoft counted as the largest company by market capitalisation in 2024 – Aramco was in third place – according to Adam Hayes, ‘Biggest Companies in World by Market Cap’, *Investopedia*, 22 January 2024.

201 Microsoft, ‘How Can’, 5, 10.

202 Matthew Zetilin, ‘Investors Are Expecting a Natural Gas Boom. Will They Get It?’, *Heatmap*, 10 December 2024; Spencer Kimball, ‘Big Oil Wants to Help Big Tech Power Artificial Intelligence Data Centers’, *CNBC*, 14 December 2024.

203 Attesting to its leadership status, Microsoft counted these emissions – so-called Scope 3 emissions – and aspired to turn them negative.

204 On this general trend, see Malm and Carton, *Overshoot*, 125; Brian Merchant, ‘How Google, Microsoft, and Big Tech Are Automating the Climate Crisis’, *Gizmodo*, 21 February 2019.

205 Barclays, ‘Frac to the Future: Oil’s Digital Rebirth’, 15 January 2020, for example, 6, 9–13.

206 Ibid., 10, 13–14.

207 Microsoft News Center, ‘ExxonMobil to Increase Permian Profitability through Digital Partnership with Microsoft’, 22 February 2019; Accenture, ‘Accenture Helps Equinor Improve Business Operations and Increase Agility with the Cloud’, 20 August 2020; Barclays, ‘Frac to the Future’, 48; Microsoft News Center, ‘Halliburton Forms Strategic Agreement with Microsoft and Accenture to Advance Digital Capabilities’, 17 July 2020; Microsoft News Center, ‘Schlumberger, Chevron and Microsoft Announce Collaboration to Accelerate Digital Transformation’, 17 September 2019; Microsoft News Center, ‘Petrofac Selects Microsoft IoT Toolkit to Build Digitally Transformative Connected Construction Platform’, 30 January 2020; PR Newswire, ‘Infosys Collaborates with Archrock for Digital Technology Integration’, 7 June 2021.

208 Microsoft News Center, ‘Microsoft Demonstrates the Power of AI and Cloud to Oil and Gas Players, at ADIPEC 2018’, 12 November 2018.

209 *Saudi Gazette*, ‘Microsoft “the Digital Transformation Partner” IPTC’, 21 January 2020; Maddie Stone, ‘While Microsoft Was Making Its Climate Pledge, It Was Sponsoring an Oil Conference’, *Vice*, 24 January 2020.

210 Darryl Willis and Lucas Joppa, ‘Working Toward a Net Zero Future: Evolving Our Work with Energy Companies’, Official Microsoft Blog, 10 March 2022. Microsoft added the proviso that the fossil fuel companies in question must ‘have publicly committed to net zero carbon targets’ – commitments not worth the website they were written on, obviously.

211 Azam Zaidi, ‘Unleashing Innovation: The Impact of Microsoft Azure on Oil and Gas Industry Automation’, *LinkedIn*, 11 April 2023.

212 Maddie Stone, ‘Inside the Worker-Led Effort to Get the World’s Most Valuable Company to Stop Helping the Oil and Gas Industry Drill’, *Grist*, 8 May 2021.

213 Maddie Stone, ‘Microsoft’s Ambitious Climate Goal Forgets about Its Oil Contracts’, *Grist*, 21 May 2020.

214 On this dynamic, see further Malm and Carton, *Overshoot*, 99–136.

215 Shopify, ‘2022 Climate Report’, 2023, 14–15, 21; and see further Ketan Joshi, ‘Why Shopify Is Bursting with Enthusiasm for Carbon Removal’, 24 November 2023.

216 CDR.fyi, ‘Keep Calm’.

217 Dan Milmo, ‘Google’s emissions climb nearly 50% in five years due to AI energy demand’, *Guardian*, 2 July 2024.

218 Center for Countering Digital Hate, ‘Greenwashing on Google: How Google Profits by Cleaning Big Oil’s Reputation’, 3 November 2022.

219 Sam Biddle, ‘Google Greenwashes a Dirty Partnership with Climate-Destroying Saudi Aramco’, *The Intercept*, 17 February 2023.

220 Catherine Clifford, ‘JPMorgan and H&M Join Tech Giants in Buying $1 Billion of Carbon Dioxide Removal’, *Clean Tech*, 12 April 2023; Jan Huckfeldt, ‘JPMorgan Chase and Climeworks Landmark CDR Agreement Heralds New Standard in Voluntary Carbon Market for Direct Air Capture’, Climeworks, 23 May 2023; Tristan Bove, ‘JPMorgan Just Bought a Massive Forest to Make Money – And Not Just from the Timber’, *Fortune*, 1 February 2023; Lamar Johnson, ‘JPMorgan Retakes Title as Top Fossil-Fuel Financier, Nonprofit Says’, *Banking Dive*, 15 May 2024. In 2022, the Royal Bank of Canada held the top position, but this might have been due to imperfect methods of ranking: see Johnson, ‘JPMorgan Retakes’.

221 Kenza Bryan, ‘Energy Crisis Is Forcing Climate Targets Off-Track, JPMorgan Says’, *Financial Times*, 22 December 2022; cf. Kenza Bryan, ‘JPMorgan Shifts Climate Goalposts’, *Financial Times*, 20 November 2023.

222 Taylor Wright, presentation at Carbon Unbound conference, New York, 23 May 2024.

223 *France24*, 'McKinsey and Company Pushes Fossil Fuel Interests as Advisor to UN Climate Talks, Whistleblowers Say', 7 November 2023; *Corporate Europe Observatory*, 'COP28 Facilitates Fossil Fuel Frenzy', 19 December 2023. See also, for example, Chloé Farand, 'Leaks Reveal How McKinsey Drives African Climate Agenda', *Climate Home News*, 27 November 2023.

224 Kenza Bryan and Brooke Masters, 'BlackRock and Vanguard Tell UK Inquiry They Will Not Quit Fossil Fuel Investments', *Financial Times*, 18 October 2022.

225 XPrize, '$100M Prize for Carbon Removal', 2024 (emphasis added).

226 Peter Diamandis, 'Elon Musk Climate Change Solution: The Real Risks We Face', YouTube, 18 November 2021.

227 Francesca Landini, 'Elon Musk Says Oil and Gas Should Not Be Demonized', *Reuters*, 16 December 2023.

228 Trisha Thadani, Clara Ence Morse and Maeve Reston, 'Elon Musk Donated $288 Million in 2024 Election, Final Tally Shows', *Washington Post*, 31 January 2025.

229 Bill McKibben, 'The Dumbest Climate Conversation of All Time: Trump and Musk', *The Crucial Years*, 13 August 2024.

230 Quotations in ibid.; and cf. for example, Oliver Milman, '"The Dumbest Climate Conversation of All Time": Experts on the Musk-Trump Interview', *Guardian*, 13 August 2024.

231 On this integration, see further Malm and Carton, *Overshoot*, 131–6.

232 Shukla et al. (eds), *Climate Change* 2022, 36, 114, 1261–5. See further William F. Lamb, 'The Size and Composition of Residual Emissions in Integrated Assessment Scenarios at Net-Zero CO_2', *Environmental Research Letters* (2024) 19: 1–11.

233 Holly Jean Buck, Wim Carton, Jens Friis Lund and Nils Markusson, 'Why Residual Emissions Matter Right Now', *Nature Climate Change* (2023) 13: 351–8.

234 International Energy Agency, 'Net Zero Roadmap: A Global Pathway to Keep the 1.5 °C Goal in Reach – 2023 Update', 2023, 62. Another standard-bearer of mainstream climate ambition, the Science-Based Targets Initiative – an organisation that helped private companies set climate targets – aimed for a maximum of 10 per cent. Science-Based Targets Initiative, 'SBTi Corporate Net-Zero Standard', March 2024.

235 Rosalie Arendt, 'Residual Carbon Emissions in Companies' Climate Pledges: Who Has to Reduce and Who Gets to Remove?', *Climate Policy* (2024) 24: 1195–1210; Microsoft, '2020 Environmental Sustainability Report: A Year of Action', 16.

236 See further Jens Friis Lund, Nils Markusson, Wim Carton and Holly Jean Buck, 'Net Zero and the Unexplored Politics of Residual Emissions', *Energy Research and Social Science* (2023) 98: 1–6.

237 Buck et al., 'Why Residual'.

238 For projected increases in emissions from aviation and cement, see, for instance, Friedlingstein et al., 'Global Carbon Budget 2023', 5321–2.

239 Stefan Gössling, 'Celebrities, Air Travel, and Social Norms', *Annals of Tourism Research* (2019) 79: 10. Other calculations put his footprint for 2018 at more than 7,000 tonnes; never completely precise, the one thing certain about these numbers is that they are huge. Beatriz Barros and Richard Wilk, 'The Outsized Carbon Footprints of the Super-Rich', *Sustainability: Science, Practice and Policy* (2021) 17: 318.

240 The annual per capita emissions of an average inhabitant of Burundi was 0.1 tonne in the early 2020s: 'Per Capita CO_2 Emissions', Our World in Data, 2024. This means Gates' emissions represent the equivalent of those of 14,000 Burundese.

241 Violet George, 'Bill Gates Says He Can Justify Using a Private Jet', *Carbon Herald*, 9 February 2023.

242 New York Times Events, Climate Forward, ‘Bill Gates on Climate: “Are We Science People or Are We the Idiots?”’, YouTube, 22 September 2023; Gelles, ‘Can We’. Gates called Climeworks the ‘gold standard’ in removal. Kahn, ‘A Startup Battles’. He wrote about himself: ‘I’m not aware of anyone who’s investing more in direct air capture technologies.’ Gates, *How to Avoid*, 15.

243 Grubert and Talati, ‘The Distortionary Effects’, 14.

244 On this general trade-off, see also Drew Shindell and Joeri Rogelj, ‘Preserving Carbon Dioxide Removal to Serve Critical Needs’, *Nature Climate Change* (2025) 15: 452–7.

245 Na’im Merchant, ‘What Does It Mean When Oil Majors Buy Biochar?’, Nori Carbon Removal Newsroom, YouTube, 19 Mars 2024.

246 Christopher T. Reinhard, Noah J. Planavsky and Anu Khan, ‘Aligning Incentives for Carbon Dioxide Removal’, *Environmental Research Letters* (2023) 18: 2.

247 Cf. Camilla Hodgson, ‘Wealthy Investors Pile into the Carbon Market’, *Financial Times*, 11 May 2022.

248 Danny Cullenward, Grayson Badgley and Freya Chay, ‘Carbon Offsets Are Incompatible with the Paris Agreement’, *One Earth* (2023) 6: 1085.

249 See, for example, Benedict Probst, Malte Toetzke, Andreas Kontoleon et al., Systematic Assessment of the Achieved Emission Reductions of Carbon Crediting Projects’, *Nature Communications* (2024) 15: 9562.

250 Martin Cames, Ralph O. Harthan, Jürg Füssler et al., ‘How Additional Is the Clean Development Mechanism?’, Institute for Applied Ecology, March 2016, 11. Much of this had, of course, to do with the problem of additionality: would the avoided emissions or emissions reductions traded through the Clean Development Mechanism have happened anyway, even if they had not been turned into a saleable credit? Much of them would have, meaning that the gain purchased was no gain at all. This problem recedes insofar as the market moves towards durable removal, because one tonne of CO_2 would not be captured through DAC or enhanced weathering or any other such technology *in its absence* – that is, the removal on sale would be contingent on its deliberate organisation by startups (unlike forests that would grow or cooking stoves that would be electrified regardless of any projects). What does not recede from the market is the problem of inflated benefits as such.

251 Barbara Haya, ‘The California Air Resources Board’s US Forest Offset Protocol Underestimates Leakage’, California Environmental Protection Agency, 12 July 2019. Another analysis a few years later put the share at 30 per cent – considerably lower, but still a substantial number. Grayson Badgley, Jeremy Freeman, Joseph J. Hamman et al., ‘Systematic Over-Crediting in California’s Forest Carbon Offsets Program’, *Global Change Biology* (2022) 28: 1433.

252 Andrew Macintosh, Don Butler, Pablo Larraondo et al., ‘Australian Human-Induced Native Forest Regeneration Carbon Offset Projects Have Limited Impact on Changes in Woody Vegetation Cover and Carbon Removals’, *Communications Earth and Environment* (2024) 5: 1–11.

253 Patrick Greenfield, ‘Revealed: More than 90% of Rainforest Carbon Offsets by Biggest Certifier Are Worthless, Analysis Shows’, *Guardian*, 18 January 2023; and see further, for example, Thales A. P. West, Sven Wunder, Jan Börner et al., ‘Action Needed to Make Carbon Offsets from Forest Conservation Work for Climate Change Mitigation’, *Science* (2023) 381: 873–7; Barbara K. Haya, Kelsey Alford-Jones, William R. L. Anderegg et al., ‘Quality Assessment of REDD+ Carbon Credit Projects’, Berkeley Public Policy, The Goldman School, 2023; Nina Lakhani, ‘Revealed: Top Carbon Offset Projects May Not Cut Planet-Heating Emissions’, *Guardian*, 19 September 2023.

254 Ecosystem Marketplace, ‘2023 State of the Voluntary Carbon Markets Report’, 2023.

255 Microsoft, ‘Microsoft Carbon’, 4.
256 Elizabeth Willmott in Sheila Fynn, ‘Carbon Offset Programs of Companies Like Microsoft, BP Go Up in Smoke as Wildfires Decimate Forests’, *Independent*, 4 August 2021.
257 For further uncertainties about how much CO_2 was actually being removed through forestry offsets according to species, place and changing climate conditions and with what aggregate impact, see Antoine Cabon, Steven A. Kannenberg, Altaf Arain et al., ‘Cross-Biome Synthesis of Source versus Sink Limits to Tree Growth’, *Science* (2022) 376: 758–61; R. D. Yanai, C. Wayson, D. Lee et al., ‘Improving Uncertainty in Forest Carbon Accounting for REDD+ Mitigation Efforts’, *Environmental Research Letters* (2020) 15: 2–12; Kimberly A. Novick, Trevor F. Keenan, William R. L. Anderegg et al., ‘We Need a Solid Scientific Basis for Nature-Based Climate Solutions in the United States’, *PNAS* (2024) 121: 1–4. On the question of permanence and the need for net zero and offsets to pivot to durable removals, see, for example, Wim Carton, Jens Friis Lund and Kate Dooley, ‘Undoing Equivalence: Rethinking Carbon Accounting for Just Carbon Removal’, *Frontiers in Climate* (2021) 3: 1–7; Cyril Brunner, Zeke Hausfather and Reto Knutti, ‘Durability of Carbon Dioxide Removal Is Critical for Paris Climate Goals’, *Communications Earth and Environment* (2024) 5: 645; Myles Allen, David Frame, Pierre Friedlingstein et al., ‘Geological Net Zero and the Need for Disaggregated Accounting for Carbon Sinks’, *Nature* (2025) 638: 343–50.
258 See for example, Robert Mendelsohn, Robert Litan and John Fleming, ‘How to Repair the World’s Broken Carbon Offset Markets’, *Yale Environment* 360, 21 November 2021; Oliver Gordon, ‘Are Forest Carbon Offsets Worth Saving?’, *Energy Monitor*, 3 November 2023; Philippe Delacote, Tara L’Horty, Andreas Kontoleon et al., ‘Strong Transparency Required for Carbon Credit Mechanisms’, *Nature Sustainability* (2024), online first.
259 Barbara Haya in Gordon, ‘Are Forest’.
260 Danny Cullenward and David G. Victor, *Making Climate Policy Work* (Cambridge: Polity, 2020), 96.
261 Ibid., 86–8.
262 Haya et al., ‘Quality Assessment’, 2.
263 Cullenward and Victor, *Making Climate*, 88.
264 The well-informed James Temple in Temple, ‘Running Tide’. For similar developments in soil carbon, see Philipp Günther et al., ‘Carbon Farming, Overestimated Negative Emissions and the Limits to Emissions Trading in Land-Use Governance: The EU Carbon Removal Certification Proposal’, *Environmental Sciences Europe* (2024) 36: 72.
265 Reinhard, Planavsky and Khan, ‘Aligning Incentives for Carbon Dioxide Removal’, 2.
266 Cullenward and Victor, *Making Climate*, 95.
267 Interview with carbon removal investor, 19 June 2024.
268 Science-Based Targets Initiative, ‘SBTi Corporate Net-Zero Standard’, 2024; Simon Jessop, ‘Climate Target Group in Turmoil over Carbon Offsetting Plan’, *Reuters*, 10 April 2024; Joseph Winters, ‘A Climate Pledge Verifier Said It Would Allow More Carbon Offsets. Its Staff Revolted’, *Grist*, 12 April 2024; Kenza Bryan, ‘Climate Targets Oversight Group Backtracks after Staff Revolt’, *Financial Times*, 13 April 2024. The decision was thus later reversed, after an internal uproar.
269 Mariá Mediluce of the We Mean Business Coalition (on which, see Malm and Carton, *Overshoot*, 29, 88, 90) in Jessop, ‘Climate Target’.
270 Poll quoted in Winters, ‘A Climate Pledge’. For a similar critique of the stringency of the Science-Based Targets Initiative, see Chris Hocknell, ‘Science-Based Targets’ Emissions Rules Don’t Reflect the Reality’, *Climate Home News*, 12 April 2024.

271 As observed by Winters, ‘A Climate Pledge’.
272 As observed by Kenza Bryan, ‘Climate Targets Group under Fire over Bezos-Backed Carbon Offsets Decision’, *Financial Times*, 11 April 2024.
273 Kenza Bryan, ‘US Pushed Behind Scenes for Approval of Corporate Carbon Offset Plan’, *Financial Times*, 21 April 2024.
274 On the histories of these two industries, see Peter Hayes, *Industry and Ideology: IG Farben in the Nazi Era* (Cambridge: Cambridge University Press, 2001); Lee Jones, *Societies under Siege: Exploring How International Sanctions (Do Not) Work* (Oxford: Oxford University Press, 2015), 52–92; and on the shared Nazi-apartheid chemical history, Dieter Leckel, ‘Diesel Production from Fischer–Tropsch: The Past, the Present, and New Concepts’, *Energy and Fuels* (2009) 23: 2342–58. Fischer–Tropsch started off with carbon monoxide; the idea here is to do it with carbon dioxide.
275 Broecker, ‘Does Air’, p. 3.
276 Climeworks, ‘Making Unlimited Renewable Fuel a Reality’, 9 June 2020; Lufthansa Group, ‘Flying with Sunlight’, 15 May 2020; Darrell Delamaide, ‘Lufthansa Backs Swiss Effort to Develop Carbon-Neutral Aviation Fuel’, *Callaway Climate Insights*, 19 May 2020; Ilaria Grasso Macola, ‘Q&A: A Look at Europe’s First Renewable Aviation Fuel Plant with Climeworks’, *Airport Technology*, 18 June 2020; Climeworks, ‘Runway to Net Zero: Climeworks Partners with SWISS and Lufthansa Group’, *Climeworks*, 7 March 2024. On the chemistry of turning air into jet fuel, see Viola Becattini, Paolo Gabrielli and Marco Mazzotti, ‘Role of Carbon Capture, Storage, and Utilization to Enable a Net-Zero-CO_2-Emissions Aviation Sector’, *Industrial and Engineering Chemistry Research* (2021) 60: 6848–62.
277 For one survey, see Mark Peplow, ‘The Race to Recycle Carbon Dioxide’, *Nature* (2022) 603: 780–3.
278 Beuttler et al., ‘The Role of Direct’, 5.
279 Diamandis, ‘Elon Musk’.
280 ‘Written Testimony of Steve Oldham’, 4–5; and see further Stephen Leahy, ‘This Gasoline Is Made of Carbon Sucked from the Air’, *National Geographic*, 7 June 2018; Tollefson, ‘Price of Sucking’, 173.
281 Stuart Penson, ‘Shell Sees DAC Potential for Synthetic Fuels Production’, *Petroleum Economist Media Network*, 22 March 2023.
282 Robert F. Service, ‘This Former Playwright Aims to Turn Solar and Wind Power into Gasoline’, *Science*, 3 July 2019; for the technical details of his ambition, see Rob McGinnis, ‘CO_2-to-Fuels Renewable Gasoline and Jet Fuel Can Soon Be Competitive with Fossil Fuels’, *Joule* (2020) 4: 509–11. For the futurism of Prometheus, visit prometheusfuels.com.
283 Amit Malewar, ‘BMW Invests in Technology that Recycles CO_2 from the Air into Carbon-Neutral Gasoline’, *Inceptive Mind*, 11 June 2020.
284 James Temple, ‘This $1.5 Billion Startup Promised to Deliver Clean Fuels as Cheap as Gas. Experts Are Deeply Skeptical’, *MIT Technology Review*, 25 April 2022.
285 Prometheus, ‘We Made History’, 12 February 2025.
286 Li et al., ‘Critical Review’, 925.
287 See, for example, the website ‘AirMiners: The Index of Companies Mining Carbon from the Air’.
288 NRG, ‘The Shoe without a Footprint’, YouTube, 13 September 2016.
289 Websites of the companies, in order of mention: 10xbeta.com, covestra.com, airprotein.com, aircompany.com, novonutrients.com, lanzatech.com, twelve.co, adadiamonds.com, aetherdiamonds.com, gonegative.co and again aircompany.com. In anticipation of the imminent takeoff of DAC, some of these companies depended, it

should be noted, on carbon captured at smokestacks, i.e. CCS. This list is distinctly incomplete: for a fuller catalogue, see XPRIZE, 'Products', 2024.

290 In theory at least, this could be combined with playing golf on courses soaked in silicates and eating oysters to speed up carbonation.

291 L. Van Peteghem, M. Sakarika, S. Matassa et al., 'Towards New Carbon-Neutral Food Systems: Combining Carbon Capture and Utilization with Microbial Protein Production', *Bioresource Technology* (2022) 349: 1–11.

292 Paolo Gabrielli, Lorenzo Rosa, Matteo Gazzani et al., 'Net-Zero Emissions Chemical Industry in a World of Limited Resources', *One Earth* (2023) 6: 682–704; and cf. Elizabeth J. Biddinger and Miguel A. Modestino, 'Electro-Organic Syntheses for Green Chemical Manufacturing', *The Electrochemical Society Interface* (2020) 29: 43–4.

293 Rebecca Trager, 'Carbon-Negative Decking Could Lock Up CO_2 Equivalent to Taking 50,000 Cars Off the Road', *Chemistry World*, 21 March 2024; Sejal Sharma, 'Seratech Bakes Bricks Overnight Using CO_2 Captured from Factories', *Interesting Engineering*, 28 November 2023.

294 See, for example, Hills et al., 'Mineralization Technology'; Kelemen et al., 'An Overview', 4; Mark Hillsdon, 'Concrete Progress on Constructing Building to Soak Up Carbon', *Reuters*, 11 October 2023.

295 Katharine Gammon, 'Suck Carbon from the Air? US Facility Launches Novel Climate Solution', *Guardian*, 19 November 2023; and the websites: madeofair.com, carboncure.com, carbonlimit.com, carboninfinity.com. Heirloom worked on this too.

296 Ongeleigh Underwood, Laura Franzini, Annie Schonberger et al., 'Circular Carbon Market Report: 2023 Analysis', Circular Carbon Network, 2023, 37. More exactly, 638 companies were producing physical products made out of carbon, while 125 relied on funding from carbon offsets. Figures for 2024 were not available at the time of this writing.

297 Ibid.

298 Mike Leitch, 'The Carbon Removal XPRIZE Announces Their 20 Finalists', Nori Carbon Removal Newsroom, YouTube, 21 May 2024.

299 Mason et al., 'Implications of the Downstream', 2, 4; de Kleijne et al., 'Limits to Paris', 169, 177, 179; Peplow, 'The Race to Recycle', 182–3.

300 Cf. Fajardy et al., 'Negative Emissions', 5.

301 Cf. for example, Kiane de Kleijne, Steef V. Hanssen, Lester van Dinteren et al., 'Limits to Paris Compatibility of CO_2 Capture and Utilization', *One Earth* (2022) 5: 168–70; Fred Mason, Gerald Stokes, Susan Fancy and Volker Sick, 'Implications of the Downstream Handling of Captured CO_2', *Frontiers in Climate* (2023) 5: 2; Erans et al., 'Direct Air', 1392.

302 Niall Mac Dowell, Paul S. Fennell, Nilay Shah and Geoffrey C. Maitland, 'The Role of CO_2 Capture and Utilization in Mitigating Climate Change', *Nature Climate Change* (2017) 7: 244–6. Cf. Thomas Bruhn, Henriette Naims and Barbara Olfe-Kräutlein, 'Separating the Debate on CO_2 Utilisation from Carbon Capture and Storage', *Environmental Science and Policy* (2016) 60: 38–43.

303 Thomas P. Senftle and Emily A. Carter, 'The Holy Grail: Chemistry Enabling an Economically Viable CO_2 Capture, Utilization, and Storage Strategy', *Accounts of Chemical Research* (2017) 50: 473.

304 Majumdar and John Deutch, 'Research Opportunities', 808.

305 The difficulty that removal companies increasingly faced when trying to make a business exclusively from offset funding was mentioned by numerous actors in the removal space that we interviewed in the spring of 2024.

306 Leitch, ‘The Carbon Removal’.
307 Interview with carbon removal expert, 29 May 2024.
308 Interview with Nicholas Eisenberger, 2 June 2020.
309 Gallucci, ‘A Buzzy New’; Calma, ‘Why This New’.
310 Chichilnisky and Eisenberger, ‘Energy Security’, 432–3.
311 Georgiadis, ‘Female Disruptors’.
312 Interview with Carbon Iceland, 18 April 2024.
313 Rob van Straten at Carbon Unbound, 23 May 2024, New York.
314 van Straten in Vels, ‘From Harmful’.
315 Tim Sperry at Carbon Unbound, 23 May 2024 (observations by Malm).
316 From the credits front, the CEO of puro.earth, Antti Vihavainen, complained about a ‘tragedy of the commons situation’. The typical non-Microsoft company would ask: ‘Why should we care when no one else does?’
317 Not exactly scientifically rigorous, this poll was ambiguous about whether the gigatonne pertained to carbon or carbon dioxide and whether it was annual or cumulative; but the mood on display was clear.
318 Romans 7:18.
319 Maeve Allsup, ‘What Running Tide’s Demise Means for Carbon Removal’s Future’, *Latitude Media*, 24 June 2024.
320 Violet George, ‘Carbon Marketplace Nori Shuts Down’, *Carbon Herald*, 4 September 2024.
321 SVT, ’Vattenfall avbryter klimatsatsning att fånga in koldioxid’, *SVT Nyheter*, 2 December 2024.
322 For one short text displaying this desire, from the ever-sophisticated Climeworks, see Christoph Beuttler, ‘Why We Must Distinguish Between Emissions Reductions and Carbon Removals’, *Chem* (2023) 9: 3382–3.
323 Jesse Goldstein, *Planetary Improvement: Cleantech Entrepreneurship and the Contradictions of Green Capitalism* (Cambridge, MA: MIT Press, 2018).
324 Cf. Romans 7:19–25.
325 Rathi, ‘Construction Begins’.
326 McKendrick, *Scrubbing*, 165.
327 Climeworks, ‘Climeworks Launches Climate Positive Gifts’, 23 November 2020; Jan Wurzbacher in ‘Climeworks’ TOP 100 Keynote: “Stick to Your Purpose, and Eventually, You Will Achieve Your Vision’, *VentureLab*, 14 October 2020. The sums were later changed to subscriptions ranging from twenty to eighty kilograms per month, or a quantity of the customer’s own choosing. Climeworks, ‘Support the Scale-Up of Direct Air Capture’, 2024; for further discussion on the use of offsets for DAC, and the economics of that industry in particular, see Gareth Bryant and Sophie Webber, *Climate Finance: Taking a Position on Climate Futures* (Newcastle: Agenda Publishing, 2024), 93–8.
328 Interview, 29 May 2024.
329 George, ‘Bill Gates Says’.
330 Oldham planned to sell the CO_2 from Captura as input in the production of concrete and carbon fibre: Calma, ‘Meet the Fossil’.
331 Barati et al., ‘Recent Progress’, 10–11; Saravanan et al., ‘CO_2 Bio-Mitigation’, 2, 6.
332 Yang et al., ‘Biological Parts’, 4; Zahed et al., ‘Biotechnology for Carbon’, 1, 7–10.
333 Upholt, ‘Inside the Quest’.
334 Zahed et al., ‘Biotechnology for Carbon’, 8. Seaweed could, of course, be commodified too: see Pessarrodona et al., ‘Carbon Removal’, 2, 6. Somewhere between the durable and the perishable, biochar had the sales point of being a commodity in agriculture.

335 Lewis et al., ‘Regenerate Natural’.

336 Or, technically put: ‘Fully renewable systems are significantly more expensive because their low load factors do not allow efficient amortization of capital-intensive DAC plants.’ Ryan Hanna, Ahmed Abdulla, Yangyang Xu and David G. Victor, ‘Emergency Deployment of Direct Air Capture as a Response to the Climate Crisis’, *Nature Communications* (2021) 12: 2. The conclusion drawn by these authors is that DAC plants should run on fossil fuels, gas specifically. See further ibid., for example, 10.

337 Arguments made in, for example, Jennifer Wilcox and AirMiners, ‘AirMiners Conference Series – Deep Dive on Direct Air Capture with Dr. Jennifer Wilcox’, YouTube, 17 June 2020; Elk Coast Institute, ‘Direct Air Capture Mobilization Summit’, unpublished booklet, 2020, 21; Sabine Fuss, Josep G. Canadell, Philippe Ciais et al., ‘Moving toward Net-Zero Emissions Requires New Alliances for Carbon Dioxide Removal’, *One Earth* (2020) 3: 147; Lackner and Azarabadi, ‘Buying Down’, 803–5; Jonas Meckling and Eric Biber, ‘A Policy Roadmap for Negative Emissions Using Direct Air Capture’, *Nature Communications* (2021) 12: 1–6; Nicoletta Brazzola, Christian Moretti, Katrin Sievert et al., ‘Utilizing CO_2 as a Strategy to Scale Up Direct Air Capture May Face Fewer Short-Term Barriers Than Directly Storing CO_2’, *Environmental Research Letters* (2024) 19: 1–19; Smith, *Pandora’s Toolbox*, 196–7 (here coming around to support for enhanced oil recovery). ‘Very viable strategic pathway’: interview with carbon removal investor, 19 June 2024.

338 Interview with Nicholas Eisenberger, 2 June 2020. The ‘by any means necessary’ approach, so broad and so narrow, included people arguing that DAC should be allowed to run on fossil fuels to ‘push the technology down the learning curve’: Hanna et al., ‘Emergency Deployment’, 2.

339 Cf. Mac Dowell et al., ‘The Role of CO_2’, 247–8; Holly Jean Buck, ‘Should Carbon Removal Be Treated as Waste Management? Lessons from the Cultural History of Waste’, *Interface Focus* (2020) 10: 3.

340 Cf. de Kleijne et al., ‘Limits to Paris’, 179.

341 On hopes for this stimulus, see, for example, Malek Al-Chalabi and Hasan Muslemani, ‘How Carbon Trading Can Unlock Carbon Dioxide Removals’, Oxford Institute for Energy Studies, November 2023.

342 Global Energy Monitor, ‘CO_2 Enhanced’.

343 Cf. Meckling and Biber, ‘A Policy’, 2; Vanessa Núñez-López and Emily Moskal, ‘Potential of CO_2-EOR for Near-Term Decarbonization’, *Frontiers in Climate* (2019) 1: 4.

344 Clive Thompson, ‘Is Sucking Carbon Out of the Air the Solution to Our Climate Crisis?’, *Mother Jones*, November/December 2021; Meckling and Biber, ‘A Policy’, 3. See further for example, McKendrick, *Scrubbing*, 86–7; Lackner and Azarabadi, ‘Buying Down’, 8197; Jennifer Wilcox, Peter C. Psarras and Simona Liguori, ‘Assessment of Reasonable Opportunities for Direct Air Capture’, *Environmental Research Letters* (2017) 12: 1–7.

345 Argument of the company summed up in Evan Halper, ‘Clock’s Running Out on Climate Change. California Says It’s Time for Giant Carbon Vacuums’, *Los Angeles Times*, 19 April 2021.

346 David Keith, ‘David Keith’; *Economist*, ‘Can Carbon’.

347 Aparajita Datta and Ramanan Krishnamoorti, ‘Analysis of Direct Air Capture Integrated with Wind Energy and Enhanced Oil Recovery’, *Environmental Science and Technology* (2023) 57: 2089–90.

348 Cf. Grubert and Talati, ‘The Distortionary Effects’, 14–15.

349 As argued in various ways in, for example, Beuttler et al., ‘The Role of Direct’, 5; Holly Jean Buck, ‘Mining the Air: Political Ecologies of the Circular Carbon Economy’, *EPE: Nature and Space* (2022) 5: 1093–5; Jan Mertens, Christian Breyer, Katrin Arning et al., ‘Carbon Capture and Utilization: More Than Hiding CO_2 for Some Time’, *Joule*, 447–8; James Temple, ‘Why Concerns over the Sustainability of Carbon Removal Are Growing’, *MIT Technology Review*, 29 February 2024.

350 Interview with Climeworks representative; cf. for example, Keith ‘Why Capture’, 1655; Lackner et al. ‘The Urgency of the Development’, 13161.

351 Temple, ‘This $1.5 Billion’.

352 Interview with land-based carbon removal startup, 10 June 2024.

353 Interview with enhanced weathering startup, 19 May 2024.

354 Interview with carbon removal expert, 11 June 2024.

355 Oliver Geden, ‘The State of CDR 2.0’, Climeworks Carbon Removal Summit 2024, 7 June 2024 (as observed by Ulrika Winter). For further evidence of this gloomy mood about deficient demand and desperate hope for the state to step in, see Pu Yang, Sam Fankhauser, Stephen M. Smith et al., ‘Policy Support for BECCS and DACCS in Europe: The View of Market Participants’, *Environmental Research Letters* (2024) 19: 1–14.

356 This kind of reliance on the state would not, however, depart from how capital has operated in recent decades: see Costas Lapavitsas and the EReNSEP Writing Collective, *The State of Capitalism: Economy, Society, and Hegemony* (London: Verso, 2023).

357 On the absence of such steps – and the urgent need for them, if any market would ever come about – see Nan Wang, Keigo Akimoto and Gregory F. Nemet, ‘What Went Wrong? Learning from Three Decades of Carbon Capture, Utilization and Sequestration (CCUS) Pilot and Demonstration Projects’, *Energy Policy* (2021) 158: 1–8; On the inclusion of carbon removal in the EU emissions trading scheme: Kate Abnett, ‘EU Considers Bringing Emissions Removal Credits into Carbon Market’, *Reuters*, 17 April 2024.

358 See for example, Jon Gertner, ‘The Swiss Company’; Lackner et al., ‘The Urgency of the Development’, 13160; Keith, ‘Why Capture’, 1655.

359 Interview with Nicholas Eisenberger, 2 June 2020.

360 Peter H. Diamandis, ‘The Promise of Direct Air Capture: Making Stuff Out of Thin Air’, *Singularity Hub*, 23 August 2019.

361 M. Anaam Hashmi and Mohammed Al-Habib, ‘Sustainability and Carbon Management Practices in the Kingdom of Saudi Arabia’, *Journal of Environmental Planning and Management* (2013) 56: 144.

362 Emre Hatipoglu and Jitendra Roychoudhury, ‘Reframing the Net-Zero Debate from Obligation to Opportunity: The Promise of the Circular Carbon Economy’, in Geoffrey Wood, Vincent Onyango, Komali Yenneti and Maria Anastasia Liakopoulu (eds), *The Palgrave Handbook of Zero Carbon Energy Systems and Energy Transitions* (Cham: Palgrave Macmillan, 2023), 2, 4 (quotation from 4); Thamir Al Shehri, Jan Frederik Braun, Nicholas Howarth et al., ‘Saudi Arabia’s Climate Change Policy and the Circular Carbon Economy Approach’, *Climate Policy* (2023) 23: 152–5. With reference to the 2006 conference: ‘It is unclear what has been accomplished by Saudi Aramco and other Saudi business enterprises since this historic event.’ Hashmi and Al-Habib, ‘Sustainability and Carbon’, 144–5. The idea might have been biding its time during the 2010s.

363 On the origins of this idea in previous ideas of a circular economy, see Buck, ‘Mining the Air’, 1087–9.

364 International Energy Forum [based in Riyadh], ‘The Circular Carbon Economy’, *IEF Insight Brief*, March 2020, 2, 4.

365 Prince Abdul Aziz bin Salman Al-Saud in Frank Kane, ‘Circular Carbon Economy Holds Promise in Battle Against Global Warming’, *Arab News*, 25 July 2020.

366 For example, Nadia Yusuf and Miltiadis D. Lytras, ‘Competitive Sustainability of Saudi Companies through Digitalization and the Circular Carbon Economy Model: A Bold Contribution to the Vision 2030 Agenda in Saudi Arabia’, *Sustainability* (2023) 15: 5; Al Shehri et al., ‘Saudi Arabia’s’, 155, 164; Hatipoglu and Roychoudhury, ‘Reframing the Net-Zero’, 1.

367 Al-Saud in Kane, ‘Circular Carbon’ (emphases added). Or: here are some ‘innovative ways to monetize each barrel’, in the words of Nasser of Aramco. Amin H. Nasser, ‘Lifting the Hood on the Real Future Facing the Petroleum Industry’, Aramco, 6 March 2018.

368 For example, Aramco, ‘Circular Carbon Economy’, 2024; Aramco, ‘Technology Development: Carbon Management’, 2020; Aramco, ‘World’s First Blue Ammonia Shipment Opens New Route to a Sustainable Future’, 27 September 2020; and see further Hatipoglu and Roychoudhury, ‘Reframing the Net-Zero’, 17; Al Shehri et al., ‘Saudi Arabia’s’, 153, 161–2; As for the fourth *r* – ‘remove’ – the main example remained the mangroves. For circular carbon economy elsewhere in the Gulf, namely Qatar, see Ahmed A. Khalifa, Abdul-Jalil Ibrahim, Abdulkarem I. Amhamed and Muftah H. El-Nas, ‘Accelerating the Transition to a Circular Economy for Net-Zero Emissions by 2050: A Systematic Review’, *Sustainability* (2022) 14: 1–20.

369 Circular Carbon Network, ‘Why Now? Sparking a Modern Industrial Revolution’, 2019.

370 See the excellent Ellen Palm, Joachim Peter Tilsted, Valentin Vogl and Alexandra Nikoleris, ‘Imagining Circular Carbon: A Mitigation (Deterrence) Strategy for the Petrochemical Industry’, *Environmental Science and Policy* (2024) 151: 1–14. Cf. Ibrahim Eryazici, Narayan Ramesh and Carlos Villa, ‘Electrification of the Chemical Industry: Materials Innovations for a Lower Carbon Future’, *MRS Bulletin* (2021) 46: 1201, 1203.

371 Hatipoglu and Roychoudhury, ‘Reframing the Net-Zero’, 5; Beuttler et al., ‘The Role of Direct’, 5.

372 L. R. López, P. Dessì, A. Cabrera-Codony et al., ‘Indoor CO_2 Direct Air Capture and Utilization: Key Strategies towards Carbon Neutrality’, *Cleaner Engineering and Technology* (2024) 20: 1–20; Roland Dittmeyer, Michael Klumpp, Paul Kant and Geoffrey Ozin, ‘Crowd Oil not Crude Oil’, *Nature Communications* (2019) 10: 1–8.

373 Dittmeyer et al., ‘Crowd Oil’.

374 Karl Marx, *Capital: A Critique of Political Economy. Volume III* (London: Penguin, 1991 [1894]), 195.

375 Ibid., 196.

376 Ibid., 199

377 Ibid., 198.

378 See for example, Shengqing Xu and Shuiping Dai, ‘CCUS as a Second-Best Choice for China’s Carbon Neutrality: An Institutional Analysis’, *Climate Policy* (2021) 21: 927, 931; Nur Firdaus and Akihisa Mori, ‘Stranded Assets and Sustainable Energy Transition: A Systematic and Critical Review of Incumbents’ Response’, *Energy for Sustainable Development* (2023) 73: 79, 81; Mertens et al., ‘Carbon Capture’, 448; Palm et al., ‘Imagining Circular’, 6; Zumbraegel, *Political Power*, 149, 241.

379 Buck, ‘Should Carbon’, 3; and cf. Buck, *Ending Fossil*, 17–19.

380 Rob van Straten at Carbon Unbound, 23 May 2024, New York.

381 Marx, *Capital. Volume III*, 966.

382 Sigmund Freud, ‘Character and Anal Erotism’, in *The Standard Edition of the Complete Psychological Works of Sigmund Freud: Volume IX* (London: Vintage, 2001 [1908]), 174.
383 For some brilliant reflections on the scatological nature of capital accumulation as such, see Adrian Johnston, *Infinite Greed: The Inhuman Selfishness of Capital* (New York: Columbia University Press, 2024), 82–8.
384 Ibid., 82.
385 His attempt to clean himself with the goose might be a picture of negative emissions technologies (perhaps natural climate solutions more particularly).
386 With thanks to Sebastian Budgen, who coined this term.
387 Parenti, ‘A Left Defence’, 131.
388 Theodor Adorno, *Philosophical Elements of a Theory of Society* (Cambridge: Polity, 2019 [1964]), 136; Theodor Adorno, *Negative Dialectics* (London: Bloomsbury, 2014 [1966]), 159.
389 Adorno, *Negative Dialectics*, 178.

12. The Logic of the Magic

1 Insightful reflections on this paradox can be found in several contributions to Andrew Biro (ed.), *Critical Ecologies: The Frankfurt School and Contemporary Environmental Crises* (Toronto: University of Toronto Press, 2011), not the least the editor’s introduction.
2 Goldstein, *Planetary Improvement*, 64, 27. Cf. for example, 141, 157.
3 Tito Jankowski, ‘How to Get to One Billion Tonnes Removed’, Carbon Removal Basel, YouTube, 9 May 2023.
4 Walter Benjamin, ‘Capitalism as Religion’, in *Selected Writings, Volume 1: 1913–1926* (Cambridge, MA: Harvard University Press, 1996), 288–9. For an illuminating exegesis, see Michael Löwy, ‘Capitalism as Religion: Walter Benjamin and Max Weber’, *Historical Materialism* (2009) 17: 60–73; and further Johnston, *Infinite Greed*, 239–41.
5 It should be added that Freud’s theory of magic – and technology as magic – appears to be virtually completely absent from contemporary Freudian theorisations of technology: see for example, Hub Zwart, ‘Auxiliary Organs and Extimate Implants: Coming to Terms with Technology from a Psychoanalytical Perspective’, in David M. Goodman and Matthew Clemente (eds), *The Routledge International Handbook of Psychoanalysis, Subjectivity, and Technology* (New York: Routledge, 2024), 89–100; Stephen Lugar, ‘Cruel Optimization: Interrogating Technology’s Optimization of Human Being’, in ibid., 379–89. But magic is a theme among many in the most powerful work of such theorisation – possibly of any theorisation of technology – in recent years: Richard Frankel and Victor J. Krebs, *Human Virtuality and Digital Life: Philosophical and Psychoanalytical Investigations* (Abingdon: Routledge, 2022).
6 Sigmund Freud, ‘The Question of a *Weltanschauung*’, in ‘New Introductory Lectures on Psychoanalysis’, in *The Standard Edition of the Complete Psychological Works of Sigmund Freud: Volume XXII* (London: Vintage, 2001), 165 (emphasis in original).
7 Sigmund Freud, *Totem and Taboo: Some Points of Agreement between the Mental Lives of Savages and Neurotics* (London: Routledge & Kegan Paul, 1960 [1912–13]), 81.
8 Ibid., 80.
9 Ibid., 78, 81; Freud, ‘The Question of a *Weltanschauung*’, 165.
10 Freud, *Totem and Taboo*, 91.

11 Ibid., 85 (emphasis added).
12 Freud, ‘The Question of a *Weltanschauung*’, 166.
13 Freud, *Totem and Taboo*, 83.
14 Ibid., 89.
15 Freud, ‘The Question of a *Weltanschauung*’, 177. ‘Technology and narcissism are inextricably bound. Technology feeds our narcissism just as much as narcissism drives our uses of technology’: Frankel and Krebs, *Human Virtuality*, 118.
16 Freud, *Totem and Taboo*, 81 (emphasis added).
17 Cf. ibid., 88.
18 Freud, *Totem and Taboo*, 87.

13. God from the Machine

1 Cf. Timothy M. Lenton, ‘Can Emergency Geoengineering Really Prevent Climate Tipping Points?’, in Jason J. Blackstock and Sean Low (eds), *Geoengineering Our Climate? Ethics, Politics and Governance* (Abingdon: Routledge, 2018), 43.

2 Stephen Markley, *The Deluge* (New York: Simon & Schuster, 2022), 349–77.

3 For some basic scenarios of such cascades, see Kemp et al. ‘Climate Endgame’, 3, 6–7.

4 Cf. James Patterson, Carina Wyborn, Linda Westman et al., ‘The Political Effects of Emergency Frames in Sustainability’, *Nature Sustainability* (2021) 4: 845.

5 Lucy Holmes McHugh, Maria Carmen Lemos and Tiffany Hope Morrison, ‘Risk? Crisis? Emergency? Implications of the New Climate Emergency Framing for Governance and Policy’, *WIREs Climate Change* (2021) 12: 2; Charles R. Corbett, ‘The Climate Emergency and Solar Geoengineering’, *Harvard Environmental Law Review* (2022) 46: 198–9, 204, 215–20.

6 Cf. the distinction between ‘emergency-as-strategy’ and ‘emergency-as-reaction’ in Patterson et al., ‘The Political Effects’, 842; and Holmes McHugh and Hope Morrison, ‘Risk? Crisis?’, 6.

7 Patterson et al., ‘The Political Effects’, 845.

8 Or *PNAS* and its sister journals. ‘Modern imperialism is embodied by industrial capitalism, which prioritises resource extraction and maximising profit. This paradigm is deeply embedded in the fabric of global affairs, influencing international trade, political dynamics, and the economic framework of nations,’ followed by a note pointing the reader to Lenin’s *Imperialism, the Highest Stage of Capitalism*. Charles Fletcher, William J. Ripple, Thomas Newsome et al., ‘Earth at Risk: An Urgent Call to End the Age of Destruction and Forge a Just and Sustainable Future’, *PNAS Nexus* (2024) 3: 2. This article was noteworthy for being signed by some of the dignitaries of contemporary climate science, notably David A. King, Michael E. Mann and Naomi Oreskes. The distance between Leninism and such science shrank on many fronts.

9 Gao et al., ‘Exploration of a Novel’, 227.

10 Hanna et al., ‘Emergency Deployment’, 2.

11 Ibid., 4.

12 Ibid., 2.

13 For example, David W. Keith and Peter J. Irvine, ‘Solar Geoengineering Could Substantially Reduce Climate Risks: A Research Hypothesis for the Next Decade’, *Earth’s Future* (2016) 4: 551; Maria Belaia, Juan B. Moreno-Cruz and David W. Keith, ‘Optimal Climate Policy in 3D: Mitigation, Carbon Removal, and Solar Geoengineering’, *Climate Change Economics* (2021) 12: 4.

14 The attractions of geoengineering in such a situation have been regularly noticed in the literature: see, for example, Nils Markusson, Franklin Ginn, Navraj Singh Ghaleigh and Vivian Scott, ‘“In Case of Emergency Press Here”: Framing Geoengineering as a Response to Dangerous Climate Change’, *WIREs Climate Change* (2014) 5: 281–90; Joshua Horton, ‘The Emergency Framing of Solar Geoengineering: Time for a Different Approach’, *The Anthropocene Review* (2015) 2: 147–51; Holly Buck, Oliver Geden, Masahiro Sugiyama and Olaf Corry, ‘Pandemic Politics: Lessons for Geoengineering’, *Communications Earth and Environment* (2020) 1: 2–3; Jesse Reynolds, ‘Is Solar Geoengineering Ungovernable? A Critical Assessment of Government Challenges Identified by the Intergovernmental Panel on Climate Change’, *WIREs Climate Change*

(2021) 12: 5; Katharine Ricke and Anthony Harding, ‘How May Solar Geoengineering Impact Global Prospects for Climate Change Mitigation?’, *Oxford Review of Economic Policy* (2023) 39: 829; Corbett, ‘The Climate Emergency’, 235–47.

15 Lenton, ‘Can Emergency’, 44; see further 45–7.

16 Fiona Harvey, ‘Destruction of World’s Forests Increased Sharply in 2020’, *Guardian*, 31 March 2021.

17 Paul Crutzen, ‘Albedo Enhancement by Stratospheric Sulfur Injections: A Contribution to Resolve a Policy Dilemma?’, *Climatic Change* (2006) 77: 211–19. On the rise of geoengineering research and the role of Crutzen’s article, see, for example, Eli Kintisch, *Hack the Planet: Science’s Best Hope – or Worst Nightmare – for Averting Climate Catastrophe* (Hoboken: Wiley, 2014), 1–99; Jeff Goodell, *How to Cool the Planet: Geoengineering and the Audacious Quest to Fix Earth’s Climate* (Boston: Houghton Mifflin Harcourt, 2010), 2–16; Clive Hamilton, *Earthmasters: The Dawn of the Age of Climate Engineering* (New Haven: Yale University Press, 2013), 14–19; Christopher W. Belter and Dian J. Seidel, ‘A Bibliometric Analysis of Climate Engineering Research’, *WIREs Climate Change* (2013) 4: 417–27; Ken Caldeira and Govindasamy Bala, ‘Reflecting on 50 Years of Geoengineering Research’, *Earth’s Future* (2017) 5: 10–17; Ina Möller, ‘Winning Hearts and Minds? Explaining the Rise of the Geoengineering Idea’, in Sapinski et al., *Has It*, 21–33.

14. An Idea with Time on Its Side

1 Neil Stephenson, *Termination Shock* (London: The Borough Press, 2021), 696.

2 Julia Simon, ‘Startups Want to Cool Earth by Reflecting Sunlight. There Are Few Rules and Big Risks’, NPR, 28 April 2024.

3 Alejandro De La Garza, ‘Inside a Controversial Startup’s Risky Attempt to Control Our Climate’, *Time*, 21 February 2023.

4 ‘Cooling Credits: A Cost-Effective Solution for Climate Change – Make Sunsets’, Make Sunsets, 2024.

5 De La Garza, ‘Inside a Controversial’.

6 Julia Simon, ‘Hacking the Sun: Solar Geoengineering… with Few Rules’, *LAist*, 21 April 2024.

7 ‘Make Sunsets’, Make Sunsets, 2024.

8 ‘Current Climate Efforts Need Time, a Luxury Only Stratospheric Aerosol Injection Can Provide’, Make Sunsets, 2024.

9 Interview, Luke Iseman, 5 October 2023 (carried out by James Mace-Moore and Asmaa Elsouda).

10 ‘Make Sunsets’, Make Sunsets.

11 Comment by Brian Vallelunga on ‘Cooling Credits’, Make Sunsets.

12 Vallelunga of the company Doppler. ‘Developing SecretOps, Starting with Developers’, Doppler, 2024.

13 Douglas Fox, ‘It’s Time to Engineer the Sky’, *Scientific American*, 1 October 2023; De La Garza, ‘Inside a Controversial’; Simon, ‘Startups Want’. They were self-avowedly ‘not afraid of controversy or challenges’. Make Sunsets, ‘Who’, 2024.

14 Cassandra Garrison, ‘Insight: How Two Weather Balloons Led Mexico to Ban Solar Geoengineering’, *Reuters*, 27 March 2023; Justine Calama, ‘Mexico Bans Solar Geoengineering Experiments after Startup’s Field Tests’, *The Verge*, 18 January 2023.

15 Simon, ‘Hacking the Sun’.

16 James Temple, ‘A Startup Says It’s Begun Releasing Particles into the Atmosphere, In an Effort to Tweak the Climate’, *MIT Technology Review*, 24 December 2022.
17 De La Garza, ‘Inside a Controversial’.
18 ‘Limited Edition: First US Stratospheric Aerosol Injection Balloon Piece’, Make Sunsets, 2024.
19 ‘Big Bertha’, Make Sunsets,2024; ‘Geoengineer It Yourself’, 2024.
20 ‘Tiny Party Pack’, Make Sunsets, 2024.
21 Fox, ‘It’s Time’.
22 Iseman in Temple, ‘A Startup’.
23 Theodor W. Adorno and Max Horkheimer, *Dialectic of Enlightenment* (London: Verso, 2008 [1944]), 144. In amusement of this kind, ‘any logical connection calling for mental effort is painstakingly avoided’. Ibid., 137. All it does ‘is to confirm the victory of technological reason over truth’. Ibid., 138.
24 See, for example, Philip Drost, ‘This Company Wants to Cool the Planet One Balloon at a Time. Some Scientists Aren’t Buying It’, CBC Radio, 17 November 2024; De La Garza, ‘Inside a Controversial’; Temple, ‘A Startup’.
25 ‘Who’, Make Sunsets.
26 Unless one counts the murky, inconsequential small-scale experiment in 2009 by Yuri Izrael, on whom more below. It appears to have featured a helicopter burning some mixture of petroleum products close to the ground and generating a toxic cloud of smoke. Fleming, *Fixing the Sky*, 255–6. Iseman and Song were, naturally, very proud of their status as pioneers: see, for example, David Gelles, ‘Silicon Valley Renegades Pollute the Sky to Save the Planet’, *New York Times*, 25 September 2024.
27 Ian Bott, Alice Hancock and Aime Williams, ‘Climate Engineering: A Quick Fix or a Risky Distraction?’, *Financial Times*, 1 September 2023.
28 Iseman interviewed by James Mace-Moore, as quoted in James Mace-Moore, ‘Vanguard for a Blue Sky: Analysing Stratospheric Aerosol Injection and London’s Climate Movement’, master’s thesis in human ecology, Lund University, 2024, 83.
29 James Temple, ‘Researchers Launched a Solar Geoengineering Test Flight in the UK Last Fall’, *MIT Technology Review*, 1 March 2023.
30 Francesca Albanese, ‘Anatomy of a Genocide: Report of the Special Rapporteur on the Situation of Human Rights in the Palestinian Territories Occupied since 1967’, United Nations Human Rights Council, 25 March 2024.
31 Eric Niiler, ‘Scientists Resort to Once-Unthinkable Solutions to Cool the Planet’, *Wall Street Journal*, 14 February 2024.
32 Niiler in *Wall Street Journal*, Tech News Briefing, ‘Could Geoengineering Cool the Planet?’, 15 February 2024.
33 Niiler, ‘Scientists Resort’.
34 Ibid.
35 Eli Waxman: Shani Ashkenazi, ‘Could Deploying a Massive Sunshade Help Curb Earth’s Rising Temperatures?’, *Calcalist*, 9 August 2023.
36 Ibid.
37 Simon, ‘Startups Want’.
38 Cf. ibid.; Awz Ventures, ‘Our Portfolio’, 2024.
39 The Toronto office was the target of direct actions from (mostly Jewish) anti-war and Palestine solidarity groups, possibly at just the moment when the Stardust experiments took place: *World Beyond War*, ‘In Toronto, Activists Take Over Office of Israeli–Canadian Tech Fund’, 3 February 2024.
40 ‘Technology Accelerated’, Awz, 2024; cf. *PR Newswire*, ‘Awz Ventures to Invest Hundreds of Millions in Multi-Use Tech via New Awz X-Seed Hub Launched in

Partnership with MAFAT', 11 August 2021.

41 'Technology Accelerated', Awz, 2024.

42 Yaron Ashkenazi, 'Unity and Hi-Tech: Israel's Tools to Recover from Hamas's War', *Jerusalem Post*, 18 October 2023. Cf. *Jerusalem Post*, 'Tech VC Founder Vows to Help Israeli National Security Post-Oct. 7', *Jerusalem Post*, 15 November 2023.

43 *PR Newswire*, 'Awz Ventures'.

44 Roni Alsheich: see *PR Newswire*, 'Awz Ventures'; Eliezer Shulman, 'Face to Face with Roni Alsheich', *Mishpacha*, 18 April 2018.

45 Sharon Gal: see *PR Newswire*, 'Awz Ventures'; Israel Defense Fund, 'Team: Management Team: Sharon Gal', 2024.

46 *Israel Defense*, 'Titan Innovations Launces $50 Million Fund Focused on Israel and US Defense', 5 March 2024.

47 Ehud Schneorson: see *PR Newswire*, 'Awz Ventures'. For some other of this man's achievements, see Thomas Brewster, 'Meet Paragon: An American-Funded, Super-Secretive Israeli Surveillance Startup That "Hacks WhatsApp and Signal"', *Forbes*, 29 July 2021; Mehul Srivastava and Kaye Wiggins, 'Cyberweapon Manufacturers Plot to Stay on the Right Side of US', *Financial Times*, 31 May 2023. On the activities of Unit 8200, see Antony Loewenstein, *The Palestine Laboratory: How Israel Exports the Technology of Occupation around the World* (London: Verso, 2023), 83–91.

48 Yuval Abraham, '"Lavender": The AI Machine Directing Israel's Bombing in Gaza', *+972 Magazine*, 3 April 2024.

49 James Woolsey, Dame Stella Rimington, Buck Revell, Stephen Harper, respectively. 'Our Team', Awz Ventures, 2024.

50 Simon, 'Startups Want'.

51 Janos Pasztor, Cynthia Scharf and Kai-Uwe Schmidt, 'How to Govern Geoengineering?', *Science* (2017) 357: 231.

52 Janos Pasztor, 'Solar Radiation Modification Governance in the Context of Temperature Overshoot', *New England Journal of Public Policy* (2023) 35: 5. Cf. for example, Janos Pasztor, 'The Need for Governance of Climate Geoengineering', *Ethics and International Affairs* (2017) 31: 419–30.

53 Andrew Freedman, 'Veteran Climate Diplomat to Advise Geoengineering Startup', *Axios*, 3 May 2024.

54 See, for example, Mohammed Tawfeeq, Kareem Khadder and Irene Nasser, 'At Least 19 Killed and More Feared Buried in Israeli Airstrike on Gaza Humanitarian Zone Targeting Hamas Militants', CNN, 10 September 2024; Elizabeth Palmer, Leigh Kiniry and Tucker Reals, 'Israeli Strikes in Gaza's al-Mawasi Humanitarian Zone Kill Dozens of Palestinians Sheltering in Tent Camp', CBS News, 10 September 2024.

55 Janos Pasztor, 'Implications for Governance of Stardust's Activities in Relation to Stratospheric Aerosol Injection', LinkedIn, 10 September 2024, 13.

56 Ibid., 3–4.

57 Ibid., 6.

58 8; cf. 15. 'The atmosphere is a global common good, and it has generally been considered that private ownership of the means to manage the global atmosphere is not appropriate. Consequently, much of the SAI [stratospheric aerosol injection] governance recommendations have suggested that private financing/ownership of relevant science should be avoided. Yet, the world is currently faced with a situation of de facto private finance funding SAI activities. A comprehensive discussion and resolution of this issue goes way beyond the scope of this report.' Ibid., 15.

59 Tyler Felgenhauer, Joshua Horton and David Keith, 'Solar Geoengineering Research on the US Policy Agenda: When Might Its Time Come?', *Environmental Politics* (2022)

31: 508. This paper was originally published in 2021 and reflects sentiments that changed dramatically after that year. For a similar complaint, see Rob Bellamy and Peter Healey, '"Slippery Slope" or "Uphill Battle"? Broadening Out Expert Scenarios of Climate Engineering Research and Development', *Environmental Science and Policy* (2018) 83: 1–10.

60 Paul Voosen, 'United States Tiptoes into Solar Geoengineering Research', *Science* (2023) 379: 628–9 (quotation from 628).

61 Mark Symes, 'Exploring Options for Actively Cooling the Earth', Advanced Research Invention Agency, 2024; Raymond Pierrehumbert and Michael Mann, 'The UK's Gamble on Solar Geoengineering Is like Using Aspirin for Cancer', *Guardian*, 12 March 2025.

62 National Academies of Science, Engineering, and Medicine [hereafter NASEM], *Reflecting Sunlight: Recommendations for Solar Geoengineering Research and Research Governance* (Washington, DC: National Academies Press, 2021). For a rapid-response critique of the report – first published in late 2021 – and its mainstreaming of geoengineering, see Jennie C. Stephens, Prakash Kashwan, Duncan McLaren and Kevin Surprise, 'The Dangers of Mainstreaming Solar Geoengineering: A Critique of the National Academies Report', *Environmental Politics* (2023) 32: 157–66.

63 *Nature* [editorial], 'Give Research into Solar Geoengineering a Chance', (2021) 593: 167.

64 Keith in Paul Voosen, 'US Needs Solar Geoengineering Research Program, Report Says', *Science* (2021) 372: 19. Cf. the excitement over the NASEM report expressed in Smith, *Pandora's Toolbox*, 328–30, 339.

65 Chris Field in Oliver Milman, 'Can Geoengineering Fix the Climate? Hundreds of Scientists Say Not So Fast', *Guardian*, 25 December 2022.

66 The White House, 'Request for Input to a Five-Year Plan for Research on Climate Intervention', 2022.

67 The White House, 'Congressionally Mandated Research Plan and an Initial Research Governance Framework Related to Solar Radiation Modification', June 2023. See further, for example, Shuchi Talati, 'A New Era of Policy in Solar Geoengineering: An Assessment of the 2023 White House Research Plan and Recommendations for Future Research Governance', Kleinman Center for Energy Policy, January 2024.

68 Christopher Flavelle, 'Environmental Group to Study Effects of Artificially Cooling Earth', *New York Times*, 10 June 2024; Corbin Hiar, 'Inside EDF's Private Meeting on Geoengineering', *E and E News*, 14 February 2024; Corbin Hiar, 'EDF Tight Lipped about New Geoengineering Research Program', *E and E News*, 12 June 2024. On the history and deeds of the Environmental Defense Fund, see Naomi Klein, *This Changes Everything: Capitalism vs. the Climate* (London: Allen Lane, 2014), 207–11, 215–17, 225–9, 235–6. This was another Keithean dream come true: he and his colleagues staked their hopes on the Fund as a 'policy entrepreneur' advancing geoengineering in Felgenhauer et al., 'Solar Geoengineering', for example, 510.

69 Solar Geoengineering Non-Use Agreement, 'Open Letter: We Call for an International Non-Use Agreement on Solar Geoengineering', 2021.

70 See ibid., 'Signatories'.

71 Sarah J. Doherty, Philip J. Rasch, Robert Wood et al., 'An Open Letter Regarding Research on Reflecting Sunlight to Reduce the Risks of Climate Change', Climate Intervention Research Letter, 27 February 2023. Cf. Bob Berwyn, '60 Scientists Call for Accelerated Research Into "Solar Radiation Management" That Could Temporarily Mask Global Warming', *Inside Climate News*, 27 February 2023

72 James E. Hansen, Makiko Sato, Leon Simons et al., ‘Global Warming in the Pipeline’, *Oxford Open Climate Change* (2023) 3: 1–33. ‘Censorship’: 19. Twenty-five metres: 24.

73 Ibid., 26. Already the authors of the seminal paper on hothouse Earth opened for this possibility: Steffen et al., ‘Trajectories of the Earth’, 8256. From a climate justice perspective, the same was done in Mary Robinson and Tara Shine, ‘Achieving a Climate Justice Pathway to 1.5°C’, *Nature Climate Change* (2018) 8: 566.

74 Govindasamy Bala, Ken Caldeira, Ines Camilloni et al., ‘One Atmosphere: An Independent Expert Review on Solar Radiation Modification Research and Deployment’, UNEP, 2023, 25. Geoengineering ‘is the only known approach that can (i) cool the planet within a few years, or (ii) limit rates or amounts of temperature increase (i.e. to meet the Paris Agreement target of well below 2°C, preferably 1.5°C), *if insufficient mitigation continues*’. Ibid., 10 (emphasis added). ‘Should the effects of climate change become broadly perceived to be unbearable, and the political pressure for governments to cool the earth rapidly become intense, SRM [solar radiation management] deployment, at that point and given the science today, is the only known means available for governments that might feasibly cool the earth on politically relevant time scales.’ Ibid., 14. Cf. for example, Catherine Clifford, ‘The World Is on Track to Overshoot 1.5 Degrees of Warming, So It’s Time to Study Reflecting Sun away from the Earth, UN Says’, CNBC, 28 February 2023.

75 Although not in the Summary for Policymakers, as noted in Talati, ‘A New Era’, 3. An early call for the IPCC to get serious on geoengineering was Andy Parker and Oliver Geden, ‘No Fudging on Geoengineering’, *Nature Geoscience* (2016) 9: 858–9.

76 Alice Hancock, ‘EU Braves Climate Storms by Wading into Geo-engineering Debate’, *Financial Times*, 23 June 2023; European Commission, ‘Scoping Paper: Solar Radiation Modification’, 3 August 2023; Holly Jean Buck and Simon Nicholson, ‘Solar Geoengineering Research in the Global Public Interest: A Proposal for How to Do It’, *One Earth* (2023) 6: 1652–64. The government of Switzerland pushed particularly hard for a new intergovernmental panel devoted exclusively to geoengineering: see Matteo Civillini, ‘Switzerland Proposes First UN Expert Group on Solar Geoengineering’, *Climate Home News*, 15 February 2024; Jonathan Watts, ‘Switzerland Calls on UN to Explore Possibility of Solar Geoengineering’, *Guardian*, 22 February 2024.

77 On this theme in Robinson’s work, with special attention to climate, see Christian P. Haines, ‘Planetary Utopianism: Geoengineering, Speculative Fiction, and the Planetary Turn’, *Textual Practice* (2023) 37: 1343–63.

78 Kim Stanley Robinson, *The Ministry for the Future* (London: Orbit, 2020), 8.

79 The Indian operation is said to have suppressed the average temperature by one degree even during the decade *after* termination; only after 2040 does a return to ‘pre-intervention levels’ set in. Ibid., 356.

80 Alejandro de la Garza, ‘Why Billionaires Are Obsessed with Blocking Out the Sun’, *Time*, 24 February 2023. On the men of private fortune funding the rush to research geoengineering in the early 2020s, see also Shuchi Talati, Holly Jean Buck and Ben Kravitz, ‘How to Address Solar Geoengineering’s Transparency Problem’, *PNAS* (2025) 122: 2.

81 de la Garza, ‘Why Billionaires’.

82 ‘Solar Geoengineering Is Becoming a Respectable Idea’, *The Economist*, 22 November 2023. Media outlets now gave the topic extensive coverage: see, for example, Erin Hale, ‘Could Imitating Volcanos Fix the Climate Crisis? Science Is Split’, *Al Jazeera*, 28 February 2023; India Bourke, ‘To Avert Climate Disaster, What If One Rogue Nation Dimmed the Sun?’, BBC, 11 October 2023; Jeremy Freeman, ‘The Best Way to Find Out If We Can Cool the Planet’, *New York Times*, 17 March 2024. On the swing in those

years, see also, for example, Robinson Meyer, ‘Scientists Are Coming Around on Geoengineering’, *Heatmap*, 21 December 2023. For a summary of the sea change in the early 2020s, see Sikina Jinnah, Shuchi Talati, Louise Bedsworth et al., ‘Do Small Outdoor Geoengineering Experiments Require Governance?’, *Science* (2024) 385: 601.

83 Pascal Lamy, ‘Geoengineering Is Worth the Risk – Provided We Regulate It Properly’, *Financial Times*, 2 September 2024. On Lamy and the Commission, see Malm and Carton, *Overshoot*, 94.

84 Keith in Simon, ‘Hacking the Sun’ (this in 2024).

85 Ariel Cohen, ‘A Bill Gates Venture Aims to Spray Dust into the Atmosphere to Block the Sun. What Could Go Wrong?’, *Forbes*, 11 January 2021. On Gates’ earlier activities in this field, see Eli Kintisch, ‘Bill Gates Funding Geoengineering Research’, *Science*, 26 January 2010.

86 See, for example, Sikina Jinnah, Louise Bedsworth, Shuchi Talati et al. ‘Stratospheric Controlled Perturbation Experiment (SCoPEx) Advisory Committee: Final Report’, SCoPEx Advisory Committee, 18 March 2024, 57–60.

87 Christina Henriksen, Johanna Sandahl, Mikael Sundström and Isadora Wronski, ‘Regarding SCoPEx Plans for Test Flights at the Swedish Space Corporation in Kiruna’, Sámiráddi, 24 February 2021. For context and a detailed account, see Aslak-Antti Oksanen, ‘Dimming the Midnight Sun? Implications of the Sámi Council’s Intervention against the SCoPEx Project’, *Frontiers in Climate* (2023) 5: 1–12.

88 The three being the Swedish Society for Nature Conservation, Friends of the Earth Sweden and Greenpeace Sweden.

89 Laurie Golding, ‘Sweden Rejects Pioneering Test of Geoengineering Tech’, *Reuters*, 31 March 2021; Shannon Osaka, ‘Why a Landmark Experiment into Dimming the Sun Got Canceled’, *Grist*, 8 April 2021.

90 Jessica McKenzie, ‘The University of Chicago’s New Climate Initiative’, *Bulletin of the Atomic Scientists*, 20 June 2024.

91 James Temple, ‘Harvard Has Halted Its Long-Planned Atmospheric Geoengineering Experiment’, *MIT Technology Review*, 18 March 2024; Jeff Tollefson, ‘Divisive Sun-Dimming Study at Harvard Cancelled: What’s Next?’, *Nature*, 27 March 2024; James Temple, ‘The Hard Lessons of Harvard’s Failed Geoengineering Experiment’, *MIT Technology Review*, 4 April 2024; Jinnah et al., ‘Do Small’, 602.

92 Sikina Jinnah et al. ‘Stratospheric Controlled Perturbation’, 235.

93 *Popular Science*, ‘How Earth-Scale Engineering Can Save the Planet’, 22 June 2005.

94 David Gells, ‘This Scientist Has a Risky Plan to Cool Earth. There’s Growing Interest’, *New York Times*, 1 August 2024.

95 Sohrab Rahvar, ‘Gravity-Assist as a Solution to Save Earth from Global Warming’, *Iranian Journal of Astronomy and Astrophysics* (2023) 10: 191–9. A pre-print was uploaded to arXiv on 10 February 2022.

96 For a comprehensive overview of space-based geoengineering schemes, see Chad M. Baum, Sean Low and Benjamin K. Sovacool, ‘Between the Sun and Us: Expert Perceptions on the Innovation, Policy, and Deep Uncertainties of Space-Based Solar Geoengineering’, *Renewable and Sustainable Energy Reviews* (2022) 158: 1–22.

97 Walter Seifritz, ‘Mirrors to Halt Global Warming?’, *Nature* 340 (1989): 603.

98 J. T. Early, ‘Space-Based Solar Shield to Offset Greenhouse Effect’, *Journal of the British Interplanetary Society* 42 (1989): 567–69.

99 Michael Noah Mautner, ‘A Space-Based Solar Screen against Climatic Warming’, *Journal of the British Interplanetary Society* (1991) 44: 135–8.

100 Cara Buckley, ‘Could a Giant Parasol in Outer Space Help Solve the Climate Crisis?’, *New York Times*, 2 February 2024.

101 Cf. Elana Kirsh, ‘Could Parasols in Space Counter Global Warming? Israeli Scientists Want to Find Out’, *The Times of Israel*, 6 February 2024. One peer-reviewed precursor to this idea was Robert G. Kennedy, Kenneth I. Roy and David E. Fields, ‘Dyson Dots: Changing the Solar Constant to a Variable with Photovoltaic Lightsails’, *Acta Astronautica* (2013) 82: 225–37.

102 István Szapudi, ‘Solar Radiation Management with a Tethered Sun Shield’, *PNAS* (2023) 120: 1–3.

103 Fuglesang Space Center, ‘HÖST 2023: Konferens och komplett rymdgymnasium’, 2023. On Fuglesang at the Esrange centre, where SCoPEx should have happened, together with the actual king of Sweden, see TT, ‘Sverige siktar mot stjärnorna som EU-bas’, *Aftonbladet*, 13 January 2023.

104 Christer Fuglesang and María García de Herreros Miciano, ‘Realistic Sunshade System at L_1 for Global Temperature Control’, *Acta Astronautica* (2021) 186: 269–79.

105 Roger Angel, ‘Feasibility of Cooling the Earth with a Cloud of Small Spacecraft near the Inner Lagrange Point (L1)’, *PNAS* (2006) 103: 17184–9.

106 MIT, ‘In Case of Climate Emergency: Deploying Space Bubbles to Block Out the Sun’, *Sci Tech Daily*, 16 July 2022.

107 Benjamin C. Bromley, Sameer H. Khan and Scott J. Kenyon, ‘Dust as a Solar Shield’, *PLOS Climate* (2023) 2: 7.

108 On the possibility of extra extraction, see ibid., 12.

109 Ibid., 17.

110 Baum et al., ‘Between the Sun’, 4–5, 10.

111 Alvia Gaskill Jr. and Charles E. Reese, ‘Global Warming Mitigation by Reduction of Outgoing Longwave Radiation through Large-Scale Surface Albedo Enhancement of Deserts Using White Plastic Polyethylene Film: The Global Albedo Enhancement Project’, SlideShare, 20 August 2003, 4. For more on Gaskill, ‘a consulting expert for industry defendants accused of mismanaging waste oil’, see Carroll Muffett and Steven Feit, ‘Fuel to the Fire: How Geoengineering Threatens to Entrench Fossil Fuels and Accelerate the Climate Crisis’, Center for International Environmental Law, 2019, 39.

112 K. W. Oleson, G. B. Bonan and J. Feddema, ‘Effects of White Roofs on Urban Temperature in a Global Climate Model’, *Geophysical Research Letters* (2010) 37: 1–7. Rooftops could also be covered with vegetation to similar effect: Allan Frei, ‘Thermal Properties of Green, White and Other Building Roof Materials and Solar Insolation: A Case Study in New York City’, *Building and Environment* (2023) 244: 1–15.

113 Sonia I. Seneviratne, Steven J. Phipps, Andrew J. Pitman et al., ‘Land Radiative Management as Contributor to Regional-Scale Climate Adaptation and Mitigation’, *Nature Geoscience* (2018) 11: 88–96; Jatin Kala, Annette L. Hirsch, Tilo Ziehn et al., ‘Assessing the Potential for Crop Albedo Enhancement in Reducing Heatwave Frequency, Duration, and Intensity under Future Climate Change’, *Weather and Climate Extremes* (2022) 35: 1–11.

114 Kala et al., ‘Assessing the Potential’, 9.

115 Ron Baiman, ‘In Support of a Renewable Energy and Materials Economy: A Global Green New Deal That Includes Arctic Sea Ice Triage and Carbon Cycle Restoration’, *Review of Radical Political Economics* (2021) 53: 615–16; Alistair Duffey, Peter Irvine, Michel Tsamados and Julienne Stroeve, ‘Solar Geoengineering in the Polar Regions: A Review’, *Earth’s Future* (2023) 11: 15–16.

116 L. Field, D. Ivanova, S. Bhattacharyya et al., ‘Increasing Arctic Sea Ice Albedo Using Localized Reversible Geoengineering’, *Earth’s Future* (2018) 6: 882–901. Cf. John C. Moore, Ilona Mettiäinen, Michael Wolovick et al., ‘Targeted Geoengineering: Local Interventions with Global Implications’, *Global Policy* (2021) 12: 110.

117 Ying Chen, Jim Haywood, Yu Wang et al., ‘Substantial Cooling Effect from Aerosol-Induced Increase in Tropical Marine Cloud Cover’, *Nature Geoscience* (2024) 17: 405; and on marine cloud brightening in general, see further NASEM, *Reflecting Sunlight*, 34–5, 44–9.

118 Andrew Anthony, ‘Melting Pot: Could “Cloud Brightening” Slow the Thawing of the Arctic?’, *Guardian*, 27 November 2022; and see further Centre for Climate Repair, University of Cambridge.

119 De La Garza, ‘Why Billionaires’; George Soros, ‘Remarks Delivered at the 2023 Munich Security Conference’, 16 February 2023.

120 Cf. US Department of Energy and National Oceanic and Atmospheric Administration, ‘Marine Cloud Brightening’, Workshop Report, November 2022, 1, 4. Marine cloud brightening as a technology for deliberate geoengineering was first proposed by John Latham, ‘Control of Global Warming?’, *Nature* (1990) 347: 339–40. There is also the option of ‘cirrus cloud thinning’, but we are leaving it out here.

121 Kate Murphy, Gary Cooper, Sarah Doherty and Rob Wood, ‘Here’s How We Could Brighten Clouds to Cool the Earth’, *IEEE Spectrum*, 7 September 2021.

122 Jeff Tollefson, ‘Can Clouds Save the Great Barrier Reef?’, *Nature* (2021), 596: 476–8; Scott A. Condie, Kenneth R. N. Anthony, Russ C. Babcock et al., ‘Large-Scale Interventions May Delay Decline of the Great Barrier Reef’, *Royal Society Open Science* (2021) 8: 19; Daniel Patrick Harrison, ‘Could “Marine Cloud Brightening” Reduce Coral Bleaching on the Great Barrier Reef?’, *The Conversation*, 16 October 2023. The *Wall Street Journal* reported on these experiments in the piece on Stardust: Niiler, ‘Scientists Resort’. As of this writing, no conclusive results were available.

123 US Department of Energy and National Oceanic and Atmospheric Administration, ‘Marine Cloud Brightening’, 5, 10.

124 Christopher Flavelle, ‘Warming Is Getting Worse. So They Just Tested a Way to Deflect the Sun’, *New York Times*, 2 April 2024; Corbin Hiar, ‘Geoengineering Test Quietly Launches Salt Crystals into Atmosphere’, *Scientific American*, 4 April 2024; Corbin Hiar and Blanca Begert, ‘A Secret Climate Experiment in Alameda’, *Politico*, 4 April 2024.

125 Blanca Begert, ‘California City Votes to Block Solar Geoengineering Experiment’, *Politico*, 6 May 2024; Christopher Flavelle, ‘Cloud Brightening Study in California Is Halted by Local Officials’, *New York Times*, 13 May 2024.

126 Soumya Karlamangla and Christopher Flavelle, ‘California City Leaders End Cloud-Brightening Test, Overruling Staff’, *New York Times*, 5 June 2024.

127 *Guardian*, ‘Bill Gates Cloud-Whitening Trials a “Dangerous Experiment”’, 14 May 2020.

128 Buck and Nicholson, ‘Solar Geoengineering’, 1653. For an early survey of resistance to experiments, including in the field of removal, see Sean Low, Chad M. Baum and Benjamin Sovacool, ‘Taking it Outside: Exploring Social Opposition to 21 Early-Stage Experiments in Radical Climate Interventions’, *Energy Research and Social Science* (2022) 90: 1–21.

15. Permanent ~~Revolution~~ Eruption

1 Smith, *Pandora’s Toolbox*, 218.

2 See for example, Alfio Alessandro Chiarenza, Alexander Farnsworth, Philip D. Mannion et al., ‘Asteroid Impact, Not Volcanism, Caused the End-Cretaceous Dinosaur

Extinction', *PNAS* (2020) 117: 17084–93.

3 Alan Robock, 'Nuclear Winter', *WIREs Climate Change* (2010) 1: 418–27; Alan Robock, 'Nuclear Winter Is a Real and Present Danger', *Nature* (2011) 473: 275–6; Joshua Coupe, Charles G. Bardeen, Alan Robock and Owen B. Toon, 'Nuclear Winter Responses to Nuclear War between the United States and Russia in the Whole Atmosphere Community Climate Model Version 4 and the Goddard Institute for Space Studies ModelE', *Journal of Geophysical Research: Atmospheres* (2019) 124: 8522–43; Lili Xia, Alan Robock, Kim Scherrer et al. 'Global Food Insecurity and Famine from Reduced Crop, Marine Fishery and Livestock Production Due to Climate Disruption from Nuclear War Soot Injection', *Nature Food* (2022) 3: 586–96.

4 P. Crutzen and J. Birks, 'The Atmosphere after a Nuclear War: Twilight at Noon', *Ambio* (1982) 11: 114–25.

5 Mautner, 'A Space-Based', 135. Crutzen, of course, was also the populariser of the term 'Anthropocene'. It is worthy of note that the idea of a nuclear winter, as originally understood, partly rested on the predicted combustion of fossil fuels in the event of a nuclear war: the bombs would set alight oil and gas tankers, platforms, wells, fields and other stores and thereby send fireballs raging across the surface and astronomic amounts of particles – both from the fossil fuels themselves and from secondary materials burned – into the sky. Crutzen and Birks, 'The Atmosphere After', 117–19.

6 Alberto Boretti, 'Reassessing the Cooling that Followed the 1991 Volcanic Eruption of Mt. Pinatubo', *Journal of Atmospheric and Solar-Terrestrial Physics* (2024) 256: 2. This paper, however, sets out to radically revise the established view of the ensuing temperature drop: see further note 48 on page 580.

7 Ben Kravitz and Douglas G. MacMartin, 'Uncertainty and the Basis for Confidence in Solar Geoengineering Research', *Nature Reviews Earth and Environment* (2020) 1: 64; Gernot Wagner, *Geoengineering: The Gamble* (Cambridge: Polity, 2021), 15; NASEM, *Reflecting Sunlight*, 31, 35, 52, 66, 206; Smith, *Pandora's Toolbox*, 202.

8 Alan Robock, Douglas G. MacMartin, Riley Duren and Matthew W. Christensen, 'Studying Geoengineering with Natural and Anthropogenic Analogs', *Climatic Change* (2013) 121: 445–458; Maxime Plazzotta, Roland Séférian, Hervé Douville et al., 'Land Surface Cooling Induced by Solar Geoengineering Constrained by Major Volcanic Eruptions', *Geophysical Research Letters* (2018) 45: 5663–71; Alan Robock, 'Benefits and Risks of Stratospheric Solar Radiation Management for Climate Intervention (Geoengineering)', *The Bridge* (2020) 50: 64; Kintisch, *Hack the Planet*, 58–67; NASEM, *Reflecting Sunlight*, 34, 38, 66–7; Smith, *Pandora's Toolbox*, 219, 225.

9 Paul Voosen, 'High-Flying Wildfire Smoke Poses Potential Threat to Ozone Layer', *Science* (2021) 374: 921–2; Sergey Khaykin, Bernard Legras, Silvia Bucci et al., 'The 2019/20 Australian Wildfires Generated a Persistent Smoke-Charged Vortex Rising Up to 35 km Altitude', *Communications Earth and Environment* (2021) 1: 1–12; Xia et al., 'Global Food Insecurity', 586.

10 Voosen, 'United States Titpoes', 628–9.

11 Smith, *Pandora's Toolbox*, 235. The design project is fully laid out in ibid., 220, 231–40; Wake Smith and Gernot Wagner, 'Stratospheric Aerosol Injection Tactics and Costs in the First 15 Years of Deployment', *Environmental Research Letters* (2018) 13: 1–11. In his later role as writer about geoengineering and climate, Smith had mixed feelings about his CV: 'I am an American, with a carbon footprint well above the already excessive national average. I spent most of my career as a commercial aviation executive, facilitating cheap jet travel for international salespeople, boozy vacationers, and imported consumer electronics alike.' Smith, *Pandora's Toolbox*, 292–3. For more on Smith, see below.

12 Smith and Wagner, ‘Stratospheric Aerosol Injection’, 8. Cf. for example, Andrew Lockley [this is Lockley of SATAN], Doug MacMartin and Hugh Hunt, ‘An Update on Engineering Issues Concerning Stratospheric Aerosol Injection for Geoengineering’, *Environmental Research Communications* (2020) 2: 1–10.

13 Wake Smith, ‘The Cost of Stratospheric Aerosol Injection through 2010’, *Environmental Research Letters* (2020) 15: 11; Smith, *Pandora’s Toolbox*, 225–6.

14 Smith, ‘The Cost of Stratospheric’, 7; cf. Smith, *Pandora’s Toolbox*, 220.

15 Smith and Wagner, ‘Stratospheric Aerosol Injection’, 4, 6; Smith, ‘The Cost of Stratospheric’, 3, 7; Smith, *Pandora’s Toolbox*, 241.

16 Smith, ‘The Cost of Stratospheric’, 10–11. Cf. Smith, *Pandora’s Toolbox*, 243. Technological developments cutting the cost of the fleet would, however, make it more widely affordable, as pointed out by Florian Rabitz, ‘Going Rogue? Scenarios for Unilateral Geoengineering’, *Futures* (2016) 84: 105–6.

17 Alan Robock, Allison Marquardt, Ben Kravitz and Georgiy Stenchikov, ‘Benefits, Risks, and Costs of Stratospheric Geoengineering’, *Geophysical Research Letters* (2009) 36: 7; Smith and Wagner, ‘Stratospheric Aerosol Injection’, 8–9; Smith, ‘The Cost of Stratospheric’, 2, 10–11; Wagner, *Geoengineering*, 9, 17–18, 24–5. ‘Incredible’: as first suggested by Scott Barrett, ‘The Incredible Economics of Geoengineering’, *Environmental and Resource Economics* (2008) 39: 45–54.

18 Stephenson, *Termination Shock*, 243–52.

19 Robock et al., ‘Benefits, Risks’, 6–7; Lockley et al., ‘An Update’. Airships and rockets were also discussed.

20 D. K. Weisenstein, D. W. Keith and J. A. Dykema, ‘Solar Geoengineering Using Solid Aerosol in the Atmosphere’, *Atmospheric Chemistry and Physics* (2015) 15: 11835–59; David W. Keith, Debra K. Weisenstein, John A. Dykema and Frank N. Keutsch, ‘Stratospheric Solar Geoengineering without Ozone Loss’, *PNAS* (2016) 113: 14910–14.

21 Bala et al., ‘One Atmosphere’, 11.

22 Or, more formally, the experiments would study the optical properties of these particles.

23 Cf. for example, Hamilton, *Earthmasters*, 67–8; Robock, ‘Benefits and Risks, 63; NASEM, *Reflecting Sunlight*, 50–1, 117, 245–50.

24 For overviews of all the climate impacts geoengineering would – on optimist expectations – stop in their tracks, see Michael C. MacCracken, ‘On the Possible Use of Geoengineering to Moderate Specific Climate Change Impacts’, *Environmental Research Letters* (2009) 4:1–14; Toby Svoboda, Peter J. Irvine, Daniel Callies and Masahiro Sugiyama, ‘The Potential for Climate Engineering with Stratospheric Sulfate Aerosol Injections to Reduce Climate Injustice’, *Journal of Global Ethics* (2019), 14: 359–60; Kravitz and MacMartin, ‘Uncertainty and the Basis’, 64.

25 Charles L. Curry, Jana Sillmann, David Bronaugh et al., ‘A Multimodel Examination of Climate Extremes in an Idealized Geoengineering Experiment’, *Journal of Geophysical Research: Atmospheres* (2014) 119: 3900–23; V. N. Aswathy, O. Boucher, M. Quaas et al., ‘Climate Extremes in Multi-Model Simulations of Stratospheric Aerosol and Marine Cloud Brightening Climate Engineering’, *Atmospheric Chemistry and Physics* (2015) 15: 9593–610; Anthony Jones, Matthew K. Hawcroft, James M. Haywood et al., ‘Regional Climate Impacts of Stabilizing Global Warming at 1.5 K Using Solar Geoengineering’, *Earth’s Future* (2018) 6: 230–51; Izidine Pinto, Christopher Jack, Christopher Lennard et al., ‘Africa’s Climate Response to Solar Radiation Management with Stratospheric Aerosol’, *Geophysical Research Letters* (2020) 47: 1–10; Anthony Harding, Gabriel A. Vecchi, Wenchang Yang and David W. Keith, ‘Impact of Solar Geoengineering on Temperature-Attributable Mortality’, *PNAS* (2024) 121: 1–9.

26 John C. Moore, Aslak Grinsted, Xiaoran Guo et al., ‘Atlantic Hurricane Surge Response to Geoengineering’, *PNAS* (2015) 112: 13794–9; Anthony C. Jones, James M. Haywood, Nick Dunstone et al., ‘Impacts of Hemispheric Solar Geoengineering on Tropical Cyclone Frequency’, *Nature Communications* (2017) 8: 1–10; Duoying Ji, Songsong Fang, Charles L. Curry et al., ‘Extreme Temperature and Precipitation Response to Solar Dimming and Stratospheric Aerosol Geoengineering’, *Atmospheric Chemistry and Physics* (2018) 18: 10133–56.

27 B. Govindasamy, K. Caldeira and P. B. Duffy, ‘Geoengineering Earth’s Radiation Balance to Mitigate Climate Change from a Quadrupling of CO_2’, *Global and Planetary Change* (2003) 37: 164–6; Peter J. Irvine, Daniel J. Lunt, Emma J. Stone and Andy Rigwell, ‘The Fate of the Greenland Ice Sheet in a Geoengineered, High CO_2 World’, *Environmental Research Letters* (2009) 4: 1–8; Patrick J. Applegate and Klaus Keller, ‘How Effective is Albedo Modification (Solar Radiation Management Geoengineering) in Preventing Sea-Level Rise from the Greenland Ice Sheet?’, *Environmental Research Letters* (2015) 10: 1–10; John C. Moore, Chao Yue, Liyun Zhao et al., ‘Greenland Ice Sheet Response to Stratospheric Aerosol Injection Geoengineering’, *Earth’s Future* (2019) 7: 1451–63; John C. Moore, Ralf Greve, Chao Yue et al., ‘Reduced Ice Loss from Greenland Under Stratospheric Aerosol Injection’, *Journal of Geophysical Research: Earth Surface* (2023) 128: 1–20. Gradualist biases might overestimate the facility of this rescue operation, as acknowledged in Moore et al., ‘Reduced Ice Loss’, 16.

28 J. Sutter, A. Jones, T. L. Frölicher et al., ‘Climate Intervention on a High-Emissions Pathway Could Delay but Not Prevent West Antarctic Ice Sheet Demise’, *Nature Climate Change* (2023) 13: 951–9; P. B. Goddard, B. Kravitz, D. G. MacMartin et al., ‘Stratospheric Aerosol Injection Can Reduce Risks to Antarctic Ice Loss Depending on Injection Location and Amount’, *Journal of Geophysical Research: Atmospheres* (2023) 128: 1–31; John C. Moore, Chao Yue, Yangxin Chen et al., ‘Multi-Model Simulation of Solar Geoengineering Indicates Avoidable Destabilization of the West Antarctic Ice Sheet’, *Earth’s Future* (2024) 12: 1–13, the latter study slightly more upbeat about what can be achieved than the others.

29 J. C. Moore, S. Jevrejeva and A. Grinsted, ‘Efficacy of Geoengineering to Limit 21st Century Sea-Level Rise’, *PNAS* (2010) 107: 15699–703.

30 Helene Muri, Jerry Tjiputra, Odd Helge Otterå et al., ‘Climate Response to Aerosol Geoengineering: A Multimethod Comparison’, *Journal of Climate* (2018) 31: 6332–3; Mengdie Xie, John C. Moore, Liyun Zhao et al., ‘Impacts of Three Types of Solar Geoengineering on the Atlantic Meridonal Overturning Circulation’, *Atmospheric Chemistry and Physics* (2022) 22: 4581–97; Daniel Pflüger, Claudia E. Wieners, Leo van Kampenhout et al., ‘Flawed Emergency Intervention: Slow Ocean Response to Abrupt Stratospheric Aerosol Injection’, *Geophysical Research Letters* (2024) 51: 4; Wake Smith, Madeline Bartels, Jasper Boers and Christian Rice, ‘On Thin Ice: Solar Geoengineering to Manage Tipping Element Risks in the Cryosphere by 2040’, *Authorea Preprints*, 18 April 2024, 1–15; Moore et al., ‘Reduced Ice Loss’, 14; Duffey et al., ‘Solar Geoengineering’, 7–11; Yating Chen, Aobo Liu and John C. Moore, ‘Mitigation of Arctic Permafrost Carbon Loss through Stratospheric Aerosol Geoengineering’, *Nature Communications* (2020) 11: 1–10; Wake Smith, Umang Bhattarai, Douglas G. MacMartin et al., ‘A Subpolar-Focused Stratospheric Aerosol Injection Deployment Scenario’, *Environmental Research Communications* (2022) 4: 9, 12; Yangxin Chen, Duoying Li, Qian Zhang et al., ‘Northern-High-Latitude Permafrost and Terrestrial Carbon Response to Two Solar Geoengineering Scenarios’, *Earth System Dynamics* (2023) 14: 55–79; Wenfu Tang, Simone Tilmes, David M. Lawrence et al.,

‘Impact of Solar Geoengineering on Wildfires in the 21st Century in CESM2/WACCM6’, *Atmospheric Chemistry and Physics* (2023) 23: 5467–86; Duoying Ji, Min Cui, Yangxin Chen and Yongjiu Dai, ‘Permafrost Response in Northern High-Latitude Regions to 1.5°C Warming and Overshoot Scenarios Achieved via Solar Radiation Modification’, *Journal of Geophysical Research: Atmospheres* (2025) 130: 1–18.

31 L. Xia, A. Robock, S. Tilmes and R. R. Neely III, ‘Stratospheric Sulfate Geoengineering Could Enhance the Terrestrial Photosynthesis Rate’, *Atmospheric Chemistry and Physics* (2016) 16: 1480–1, 1485; J. F. Tjiputra, A. Grini and H. Lee, ‘Impact of Idealized Future Stratospheric Aerosol Injection on the Large-Scale Ocean and Land Carbon Cycles’, *Journal of Geophysical Research: Biogeosciences* (2016) 121: 20–3; David W. Keith, Gernot Wagner and Claire L. Zabel, ‘Solar Geoengineering Reduces Atmospheric Carbon Burden’, *Nature Climate Change* (2017) 7: 617–19; Long Cao and Jiu Jiang, ‘Simulated Effect of Carbon Cycle Feedback on Climate Response to Solar Geoengineering’, *Geophysical Research Letters* (2017) 44: 12,484–91; Katherine Dagon and Daniel P. Schrag, ‘Quantifying the Effects of Solar Geoengineering on Vegetation’, *Climatic Change* (2019) 153: 235–51; Cheng-En Yang, Forrest M. Hoffman, Daniel M. Ricciuto et al., ‘Assessing Terrestrial Biogeochemical Feedbacks in a Strategically Geoengineered Climate’, *Environmental Research Letters* (2020) 15: 1–11.

32 Bala Govindasamy and Ken Caldeira, ‘Geoengineering Earth’s Radiation Balance to Mitigate CO_2-Induced Climate Change’, *Geophysical Research Letters* (2000) 27: 2141–2; H. Damon Matthews and Ken Caldeira, ‘Transient Climate-Carbon Simulations of Planetary Geoengineering’, *PNAS* (2007) 104: 9950; Peter J. Irvine, Ben Kravitz, Mark G. Lawrence and Helene Muri, ‘An Overview of the Earth System Science of Solar Geoengineering’, *WIREs Climate Change* (2016) 7: 817; Rick D. Russotto and Thomas P. Ackerman, ‘Energy Transport, Polar Amplification, and ITCZ Shifts in the GeoMIP GI Ensemble’, *Atmospheric Chemistry and Physics* (2018) 18: 2287–305; Ben Kravitz, Douglas G. MacMartin, Simon Tilmes et al., ‘Comparing Surface and Stratospheric Impacts of Geoengineering with Different SO_2 Injection Strategies’, *Journal of Geophysical Research: Atmospheres* (2019) 124: 7901; Abdul Malik, Peer J. Nowack, Joanna D. Haigh et al., ‘Tropical Pacific Climate Variability under Solar Geoengineering: Impacts on ENSO Extremes’, *Atmospheric Chemistry and Physics* (2020) 20: 15461, 15466, 15480; Wei Cheng, Douglas G. MacMartin, Ben Kravitz et al., ‘Changes in Hadley Circulation and Intertropical Convergence Zone under Strategic Stratospheric Aerosol Geoengineering’, *NPJ Climate and Atmospheric Science* (2022) 5: 1–11; Kravitz and MacMartin, ‘Uncertainty and the Basis’, 69; Duffey et al., ‘Solar Geoengineering’, 1, 5; Kintisch, *Hack the Planet*, 60; NASEM, *Reflecting Sunlight*, 51–3. There is another mechanism also generating tropical overcooling and polar undercooling under geoengineering, having to do with the different vertical transport of energy and temperature change – or ‘lapse rate’ in meteorological jargon: see Matthew Henry and Timothy M. Merlis, ‘Forcing Dependence of Atmospheric Lapse Rate Changes Dominates Residual Polar Warming in Solar Radiation Management Climate Scenarios’, *Geophysical Research Letters* (2020) 47: 1–8.

33 Jiu Jiang, Long Cao, Douglas G. MacMartin et al., ‘Stratospheric Sulfate Aerosol Geoengineering Could Alter the High-Latitude Seasonal Cycle’, *Geophysical Research Letters* (2019) 46: 14,153–63; NASEM, *Reflecting Sunlight*, 53.

34 P. Heckendorn, D. Weisenstein, S. Fueglistaler et al., ‘The Impact of Geoengineering Aerosols on Stratospheric Temperature and Ozone’, *Environmental Research Letters* (2009) 4: 1–12; Simone Tilmes, Rolando R. Garcia, Douglas E. Kinnison et al., ‘Impact of Geoengineered Aerosols on the Troposphere and Stratosphere’, *Journal of*

Geophysical Research (2009) 114: 5–7; V. Aquila, C. I. Garfunkel., P. A. Newman et al., 'Modifications of the Quasi-Biennial Oscillation by a Geoengineering Perturbation of the Stratospheric Aerosol Layer', *Geophysical Research Letters* (2014) 41: 1738–44; I. R. Simpson, S. Tilmes, J. H. Richter et al., 'The Regional Hydroclimate Response to Stratospheric Sulfate Geoengineering and the Role of Stratospheric Heating', *Journal of Geophysical Research: Atmospheres* (2019) 124: 12587–616; Jiang et al., 'Stratospheric Sulfate', 154, 160; NASEM, *Reflecting Sunlight*, 53–4; Bala et al., 'One Atmosphere', 18. Conversely, greenhouse gases warm the troposphere but cool the stratosphere.

35 John T. Fasullo, Simon Tilmes, Jadwiga H. Richter et al., 'Persistent Polar Ocean Warming in a Strategically Geoengineered Climate', *Nature Geoscience* (2018) 11: 910–15; Henry and Merlis, 'Forcing Dependence'. But different modelling results are reached in the older study of Govindasamy et al., 'Geoengineering Earth's', 162.

36 Govindasamy and Caldeira, 'Geoengineering Earth's', 2142; Govindasamy et al., 'Geoengineering Earth's', 157–8.

37 A. Jones, J. Haywood, O. Boucher et al., 'Geoengineering by Stratospheric SO_2 Injection: Results from the Met Office HadGEM2 Climate Model and Comparison with the Goddard Institute for Space Studies ModelE', *Atmospheric Chemistry and Physics* (2010) 10: 6002; Kravitz et al., 'Comparing Surface', 7901; Kintisch, *Hack the Planet*, 68.

38 For example, Mike Hulme, *Can Science Fix Climate Change?: A Case Against Climate Engineering* (Cambridge: Polity, 2014), 48–52, 105; Jones et al., 'Regional Climate Impacts'; Belaia et al., 'Optimal Climate', 4; NASEM, *Reflecting Sunlight*, 35–6, 50, 59.

39 For one survey, see Katharine Ricke, Jessica S. Wan, Marissa Saenger and Nicholas J. Lutsko, 'Hydrological Consequences of Solar Geoengineering', *Annual Review of Earth and Planetary Sciences* (2023) 51: 447–70. On the prior trend of intensification, cf. note 349 on page 474.

40 G. Bala, P. B. Duffy and K. E. Taylor, 'Impact of Geoengineering Schemes on the Global Hydrological Cycle', *PNAS* (2008) 105: 7664–9; D. J. Lunt, A. Ridgwell, P. J. Valdes and A. Seale, '"Sunshade World": A Fully Coupled GCM Evaluation of the Climate Impacts of Geoengineering', *Geophysical Research Letters* (2008) 35: 1–5; Simone Tilmes, John Fasullo, Jean-Francois Lamarque et al., 'The Hydrological Impact of Geoengineering in the Geoengineering Model Intercomparison Project (GeoMIP)', *Journal of Geophysical Research: Atmospheres* (2013) 118: 11036–58; Katherine Dagon and Daniel P. Schrag, 'Exploring the Effects of Solar Radiation Management on Water Cycling in a Coupled Land-Atmosphere Model', *Journal of Climate* (2016) 29: 2635–50; John T. Fasullo, Simon Tilmes, Jadwiga H. Richter et al., 'Persistent Polar Ocean Warming in a Strategically Geoengineered Climate', *Nature Geoscience* (2018) 11: 910–11; Peter J. Irvine and David W. Keith, 'Halving Warming with Stratospheric Aerosol Geoengineering Moderates Policy-Relevant Climate Hazards', *Environmental Research Letters* (2020) 15: 1–2, 6; Simpson et al., 'The Regional Hydroclimate'; Tilmes et al., 'Impact of Geoengineered', 10; Irvine et al., 'An Overview of the Earth', 818–19; NASEM, *Reflecting Sunlight*, 51–4.

41 Ju Liang and Jim Haywood, 'Future Changes in Atmospheric Rivers over East Asia under Stratospheric Aerosol Intervention', *Atmospheric Chemistry and Physics* (2023) 23: 1687–703. But the simulations reported in this study suggest that the rivers would in fact become *stronger* over north-eastern China and the Korean peninsula.

42 Pinto et al., 'Africa's Climate'; E. A. Alamou, J. E. Zandagba, E. I. Biao et al., 'Impact of Stratospheric Aerosol Geoengineering on Extreme Precipitation and Temperature

Indices in West Africa Using GLENS Simulations', *Journal of Geoengineering Research: Atmospheres* (2022) 127: 1–20.

43 Keith and Irvine, 'Solar Geoengineering', 556. One study rather suggesting an overall decrease in drying and droughts is Zhaochen Liu, Xianmei Land and Dabang Jiang, 'Stratospheric Aerosol Injection Geoengineering Would Mitigate Greenhouse Gas-Induced Drying and Affect Global Drought Patterns', *Journal of Geophysical Research: Atmospheres* (2024) 129: 1–14.

44 Angus J. Ferraro, Eleanor J. Highwood and Andrew J. Charlton-Perez, 'Weakened Tropical Circulation and Reduced Precipitation in Response to Geoengineering', *Environmental Research Letters* (2014) 9: 1–7; Lunt et al., '"Sunshade World"', 4; Pinto et al., 'Africa's Climate', 8–9; Malik et al., 'Tropical Pacific'.

45 Jim M. Haywood, Andy Jones, Nicolas Bellouin and David Stephenson, 'Asymmetric Forcing from Stratospheric Aerosols Impacts Sahelian Rainfall', *Nature Climate Change* (2013) 3: 660–5; cf. for example, Jones et al., 'Geoengineering by Stratospheric', 6003–4; Ricke et al., 'Hydrological Consequences', 454. Some modelling indicates that global warming would drive the zone northwards and geoengineering would restore it to its original place: Malik et al., 'Tropical Pacific', 15480. Most models, however, seem to suggest a dislocation: Cheng et al., 'Changes in Hadley', 6–7.

46 On the former, see Liu et al., 'Stratospheric Aerosol'. But one study has indicated reduced risk of drought in Cape Town: Romaric C. Odoulami, Mark New, Piotr Wolski et al., 'Stratospheric Aerosol Geoengineering Could Lower Future Risk of "Day Zero" Level Droughts in Cape Town', *Environmental Research Letters* (2020) 15: 1–9.

47 K. S. Krishnamohan and Govindasamy Bala, 'Sensitivity of Tropical Monsoon Precipitation to the Latitude of Stratospheric Aerosol Injections', *Climate Dynamics* (2022) 59: 151–68; Shinto Roose, Govindasamy Bala, K. S. Krishnamohan et al., 'Quantification of Tropical Monsoon Precipitation Changes in Terms of Interhemispheric Differences in Stratospheric Sulfate Aerosol Optical Depth', *Climate Dynamics* (2023) 61: 4243–58; Robock et al., 'Studying Geoengineering', 447–8; Ricke et al., 'Hydrological Consequences', 458; Liu et al., 'Stratospheric Aerosol', 2; Simpson et al., 'The Regional Hydroclimate', for example, 604, 611, 613. One modelling exercise that places the effect at the lower end is Mansi Bhowmick, Saroj Kanta Mishra, Ben Kravitz et al., 'Response of the Indian Summer Monsoon to Global Warming, Solar Geoengineering and its Termination', *Scientific Reports* (2021) 11: 8–9.

48 Pornampai Narenpitak, Siriwat Kongkulsiri, Saifhon Tomkratoke and Sirod Sirisup, 'Regional Impacts of Solar Radiation Modification on Surface Temperature and Precipitation in Mainland Southeast Asia and the Adjacent Oceans', *Scientific Reports* (2024) 14: 1–17.

49 Akihiko Ito, 'Solar Radiation Management and Ecosystem Functional Responses', *Climatic Change* (2017) 142: 53–66; Phoebe L. Zarnetske, Jessica Gurevitch, Janet Franklin et al., 'Potential Ecological Impacts of Climate Intervention by Reflecting Sunlight to Cool Earth', *PNAS* (2021) 118: 6; Xia et al., 'Stratospheric Sulfate'; Ricke et al., 'Hydrological Consequences', 461. One study expects the stimulus on photosynthesis to be very small due to limitations on nitrogen: J. F. Tjiputra et al., 'Impact of Idealized'.

50 Jonathan Proctor, Solomon Hsiang, Jennifer Burney et al., 'Estimating Global Agricultural Effects of Geoengineering Using Volcanic Eruptions', *Nature* (2018) 560: 480–3. Another study, again, reaches opposite results, because of different background assumptions: the worst-case business-as-usual scenario allowing for a greater cooling effect – hence relief from heat stress in the geoengineered scenario – and an enduring

fertilisation effect from extremely high atmospheric concentrations of CO_2: Yanchao Fan, Jerry Tjiputra, Helene Muri et al., 'Solar Geoengineering Can Alleviate Climate Change Pressures on Crop Yields', *Nature Food* (2021) 2: 373–81. For geoengineering as a potential threat to food security, cf. Teea Kortetmäki and Markku Oksanen, 'Right to Food and Geoengineering', *Journal of Agricultural and Environmental Ethics* (2023) 36: 1–17.

51 Susanne Baur, Benjamin M. Sanderson, Roland Séférian and Laurent Terray, 'Solar Radiation Modification Challenges Decarbonization with Renewable Solar Energy', *Earth System Dynamics* (2024) 15: 307–22. An earlier estimate found fuel starvation only for centralised solar power: Christopher J. Smith, Julia A. Crook, Rolf Crook et al., 'Impacts of Stratospheric Sulfate Geoengineering on Global Solar Photovoltaic and Concentrating Solar Power Resource', *Journal of Applied Meteorology and Climatology* (2017) 56: 1483–97. For the gains and victory of solar, see Malm and Carton, *Overshoot*, for example, 189–91.

52 Susanne Bauer, Benjamin M. Sanderson, Roland Séférian and Laurent Terray, 'Change in Wind Renewable Energy Potential Under Stratospheric Aerosol Injection', *Earth's Future* (2024) 12: 1–20. The extraordinary research by Susanne Bauer and her colleagues suggested that the effect would be larger and worse for solar than for wind.

53 Susanne Bauer, 'How Solar Geoengineering Could Disrupt Solar and Wind Power', *Carbon Brief*, 3 October 2024.

54 Ben Kravitz, Douglas G. MacMartin and Ken Caldeira, 'Geoengineering: Whiter Skies?', *Geophysical Research Letters* (2012) 39: 1–6.

55 Elizabeth Kolbert, *Under a White Sky: The Nature of the Future* (New York: Crown, 2021).

56 C. S. Zerefos, V. T. Gerogiannis, D. Balis et al., 'Atmospheric Effects of Volcanic Eruptions as Seen by Famous Artists and Depicted in their Paintings', *Atmospheric Chemistry and Physics* (2007) 7: 4027–42.

57 Robock et al., 'Benefits, Risks', 2.

58 Ben Kravitz, Alan Robock, Luke Oman et al., 'Sulfuric Acid Deposition from Stratospheric Geoengineering with Sulfate Aerosols', *Journal of Geophysical Research: Atmospheres* (2009) 114: 1–7; Utibe Effiong and Richard L. Neitzel, 'Assessing the Direct Occupational and Public Health Impacts of Solar Radiation Management with Stratospheric Aerosols', *Environmental Health* (2016) 15: 1–9; Sebastian D. Eastham, Debra K. Weisenstein, David W. Keith and Steven R. H. Barrett, 'Quantifying the Impact of Sulfate Geoengineering on Mortality from Air Quality and UV-B Exposure', *Atmospheric Environment* (2018) 187: 424–34; Daniele Visioni, Eric Slessarev, Douglas G. MacMartin et al., 'What Goes Up Must Come Down: Impacts of Deposition in a Sulfate Geoengineering Scenario', *Environmental Research Letters* (2020) 15: 1–7.

59 Simone Tilmes, Rolf Müller and Ross Salawitch, 'The Sensitivity of Polar Ozone Depletion to Proposed Geoengineering Schemes', *Science* (2008) 320: 1201–4; Robock et al., 'Studying Geoengineering', 448; Heckendorn et al., 'The Impact of Geoengineering'; Tilmes et al., 'Impact of Geoengineered', 11–21; NASEM, *Reflecting Sunlight*, 42–4, 65.

60 Keith et al., 'Stratospheric Solar'; D. K. Weisenstein, D. W. Keith and J. A. Dykema, 'Solar Geoengineering Using Solid Aerosol in the Atmosphere', *Atmospheric Chemistry and Physics* (2015) 15: 11854; Zhen Dai, Debra K. Weisenstein, Frank N. Keutsch and David W. Keith, 'Experimental Reaction Rates Constrain Estimates of Ozone Response to Calcium Carbonate Geoengineering', *Nature Communications Earth and Environment* (2020) 1: 1–8; Kravitz and MacMartin, 'Uncertainty and the Basis', 67.

61 Jonathan M. Moch, Loretta J. Mickley, Sebastian D. Eastham et al., 'Overlooked Long-Term Atmospheric Chemical Feedbacks Alter the Impact of Solar Geoengineering: Implications for Tropospheric Oxidative Capacity', *AGU Advances* (2023) 4: 1–15.

62 Robock et al., 'Benefits, Risks', 5. They could also interfere with the nucleation of cirrus clouds: Miriam Kuebbeler, Ulrike Lohmann and Johann Feichter, 'Effects of Stratospheric Sulfate Aerosol Geo-engineering on Cirrus Clouds', *Geophysical Research Letters* (2012) 39: 1–5.

63 Smith et al., 'On Thin Ice', 9–10.

64 Phillip Williamson and Carol Turley, 'Ocean Acidification in a Geoengineering Context', *Philosophical Transactions of the Royal Society A* (2012) 370: 4317–42; Tjiputra et al., 'Impact of Idealized', 14–17, 21; NASEM, *Reflecting Sunlight*, 60.

65 Pflüger et al., 'Flawed Emergency', for example, 7; and cf. P. J. Irvine, R. L Sriver and K. Keller, 'Tension between Reducing Sea-Level Rise and Global Warming through Solar-Radiation Management', *Nature Climate Change* (2012) 2: 97–9.

66 Rhonda C. Müller, Jin-Soo Kim, Hanna Lee et al., 'Radiative Forcing Geoengineering Causes Higher Risk of Wildfires and Permafrost Thawing over the Arctic Regions', *Communications Earth and Environment* (2024) 5: 1–12.

67 Tang et al., 'Impact of Solar', for example, 5472–5, 5479, 5482.

68 Cf. Jana Sillmann, Timothy M. Lenton, Anders Levermann et al., 'Climate Emergencies Do Not Justify Engineering the Climate', *Nature Climate Change* (2015) 5: 291; Applegate and Keller, 'How Effective'; Irvine et al., 'The Fate of the Greenland', 7; Lenton, 'Can Emergency', 43–4. Carbon released from thawing permafrost (whose effect on temperatures would necessitate higher doses of sulphate aerosols) cannot be recaptured: Ji et al., 'Permafrost Response'.

69 See in particular Zarnetske et al., 'Potential Ecological'; and the classic list of side effects presented in Alan Robock, '20 Reasons Why Geoengineering May Be a Bad Idea', *Bulletin of the Atomic Scientists* (2008) 64: 14–18; and cf. Raymond Pierrehumbert, 'There Is No Plan B for Dealing with the Climate Crisis', *Bulletin of the Atomic Scientists* (2019) 75: 217; Hulme, *Can Science*, for example, 98–100, 104; Irvine et al., 'An Overview', 824; Kravitz and MacMartin, 'Uncertainty and the Basis'; NASEM, *Reflecting Sunlight*, 117; Wagner, *Geoengineering*, 70–1; Müller et al., 'Radiative Forcing', 8. Modelling in the late 2010s and early 2020s kept discovering new potential side effects: for some related to disease proliferation, see Colin J. Carlson and Christopher H. Trisos, 'Climate Engineering Needs a Clean Bill of Health', *Nature Climate Change* (2018) 8: 843–5; Colin J. Carlson, Rita Colwell, Mohammad Sharif Hossain et al., 'Solar Geoengineering Could Redistribute Malaria Risk in Developing Countries', *Nature Communications* (2022) 13: 1–9.

70 Ben Kravitz in Anthony, 'Melting Pot'. Kravitz was a co-author of numerous articles on geoengineering, one of which again highlighted the incalculable uncertainties: Daniele Visioni, Ewa M. Bednarz, Walker R. Lee et al., 'Climate Responses to Off-Equatorial Stratospheric Sulfur Injections in Three Earth System Models – Part 1: Experimental Protocols and Surface Changes', *Atmospheric Chemistry and Physics* (2023) 23: 663–85.

71 'The great philosopher Donald Rumsfeld distinguishes between known unknowns and unknown unknowns.' Martin Bunzl, 'Researching Geoengineering: Should Not or Could Not?', *Environmental Research Letters* (2009) 4: 3. See further for example, Douglas G. MacMartin, Ben Kravitz, Jane C. S. Long and Philip J. Rasch, 'Geoengineering with Stratospheric Aerosols: What Do We Know after a Decade of Research?', *Earth's Future* (2016) 4: 544; Kravitz and MacMartin, 'Uncertainty and the Basis', 67.

72 On rift theory, cf. Richard York, ‘Geoengineering and Imperialism’, in Sapinski et al., *Has It*, 182; and the analysis was sketched by Holly Jean Buck in her first paper on the topic: Holly Jean Buck, ‘Geoengineering: Re-Making Climate for Profit or Humanitarian Intervention?’, *Development and Change* (2012) 43: 255. Harvey: David Harvey, *A Companion to Marx’s* Capital Volume 2 (London: Verso, 2013), 261–2.

73 Cf. Pierrehumbert, ‘There Is No’, 219.

74 Heckendorn et al., ‘The Impact of Geoengineering’, 1, 6–7, 11; Robock et al., ‘Studying Geoengineering’, 450; Robock, ‘Benefits and Risks’, 61.

75 John G. Virgin and Christopher G. Fletcher, ‘Declining Geoengineering Efficacy Caused by Cloud Feedbacks in Transient Solar Dimming Experiments’, *Journal of Climate* (2024) 37: 113–128.

76 Smith, ‘The Cost of Stratospheric’, for example, 5, 10–11; cf. Jesse L. Reynolds, Andy Parker and Peter Irvine, ‘Five Solar Geoengineering Tropes that Have Outstayed Their Welcome’, *Earth’s Future* (2016) 4: 565.

77 This has become something like common knowledge, accepted by, for example, NASEM, *Reflecting Sunlight*, 4; cf. Bala et al., ‘One Atmosphere’, 18.

78 For example, O. Boucher, J. A. Lowe and C. D. Jones, ‘Implications of Delayed Actions in Addressing Carbon Dioxide Emission Reduction in the Context of Geo-engineering’, *Climatic Change* (2009) 92: 269; Kelly E. McCusker, Kyle C. Armour, Cecilia M. Bitz and David S. Battisti, ‘Rapid and Extensive Warming Following Cessation of Solar Radiation Management’, *Environmental Research Letters* (2014) 9: 1; Florian Rabitz, ‘Governing the Termination Problem in Solar Radiation Management’, *Environmental Politics* (2019) 28: 503.

79 ‘Net’ here including the limitations of removal.

80 Here assuming precisely that the termination would be abrupt and not a gradual phase-out protracted over decades: see further below.

81 Cf. for example, Matthews and Caldeira, ‘Transient Climate-Carbon’; Andy Jones, Jim. M. Haywood, Karl Alterskjaer et al., ‘The Impact of Abrupt Suspension of Solar Radiation Management (Termination Effect) in Experiment G2 of the Geoengineering Model Intercomparison Project (GeoMIP)’, *Journal of Geophysical Research* (2013) 118: 9743–52; John Halstead, ‘Stratospheric Aerosol Injection Research and Existential Risk’, *Futures* (2018) 102: 69; McCusker et al., ‘Rapid and Extensive’, 7.

82 Andrew Ross and H. Damon Matthews, ‘Climate Engineering and the Risk of Rapid Climate Change’, *Environmental Research Letters* (2009) 4: 3; P. J. Irvine, R. L Sriver and K. Keller 2012, ‘Tension between Reducing Sea-Level Rise and Global Warming through Solar-Radiation Management’, *Nature Climate Change* (2012) 2: 97; McCusker et al., ‘Rapid and Extensive’; Matthews and Caldeira, ‘Transient Climate-Carbon’, 9949; Muri et al., ‘Climate Response’, 6331; and see further for example, William C. G. Burns, ‘Climate Geoengineering: Solar Radiation Management and its Implication for Intergenerational Equity’, *Stanford Journal of Law, Science and Policy* (2011) 4: 47–8; Jones et al., ‘The Impact of Abrupt’; Aswathy et al., ‘Climate Extremes’, 9604–6; Bhowmick et al., ‘Response of the Indian’, 2, 4, 9.

83 Victor Brovkin, Vladimir Petoukhov, Martin Claussen et al., ‘Geoengineering Climate by Stratospheric Sulfur Injections: Earth System Vulnerability to Technological Failure’, *Climatic Change* (2009) 92: 255.

84 Muri et al., ‘Climate Response’, 6333, 6338.

85 Ibid., 6336; David P. Keller, Elias Y. Feng and Andreas Oschlies, ‘Potential Climate Engineering Effectiveness and Side Effects during a High Carbon Dioxide-Emission Scenario’, *Nature Communications* (2014), 5: 6; Ito, ‘Solar Radiation’, 60.

86 Bhowmick et al., ‘Response of the Indian’, 9.

87 Christopher H. Trisos, Giuseppe Amatulli, Jessica Gurevitch et al., ‘Potentially Dangerous Consequences for Biodiversity of Solar Geoengineering Implementation and Termination’, *Nature Ecology and Evolution* (2018) 2: 475–82. Cf. for example, Ross and Matthews, ‘Climate Engineering’, 4–6.

88 Seth D. Baum, Timothy M. Maher Jr. and Jacob Haqq-Misra, ‘Double Catastrophe: Intermittent Stratospheric Geoengineering Induced by Societal Collapse’, *Environment Systems and Decisions* (2013) 33: 175.

89 Cf. Aaron Tang and Luke Kemp, ‘A Fate Worse than Warming? Stratospheric Aerosol Injection and Global Catastrophic Risk’, *Frontiers in Climate* (2021) 3: 10.

90 Masson-Delmotte et al., *Climate Change 2021: The Physical Science Basis*, 5, 854, 856, 888. For a variety of estimates on the magnitude of this effect, see Hansen et al., ‘Global Warming’, 15; cf. for example, V. Ramanathan and Y. Feng, ‘On Avoiding Dangerous Anthropogenic Interference with the Climate System: Formidable Challenges Ahead’, *PNAS* (2008) 105: 14245–50; A. H. Peace, K. S. Carslaw, L. A. Lee et al., ‘Effect of Aerosol Radiative Forcing Uncertainty on Projected Year of a 1.5°C Global Temperature Rise’, *Environmental Research Letters* (2020) 15: 1–12; H. Damon Matthews and Seth Wynes, ‘Current Global Efforts Are Insufficient to Limit Warming to 1.5°C’, *Science* (2022) 376: 1406; Pinya Wang, Yang Yang, Daokai Xue et al., ‘Aerosols Overtake Greenhouse Gases Causing a Warmer Climate and More Weather Extremes towards Carbon Neutrality’, *Nature Communications* (2023) 14: 1–11. The knowledge of the jostling stretches back to the earliest days of climate science and politics: ‘We cannot say for sure what effect the continuing build-up of carbon dioxide in the atmosphere will have on the climate. Will it turn the earth into some kind of Venusian hothouse? Or will the greenhouse effect be offset by the shielding effect of more industrial particles?’ Mostafa Tolba, ‘A Duty to Hope: New Directions for Science and Technology’, in *Sustainable Development: Constraints and Opportunities* (London: Butterworth, 1987), 52.

91 On air pollution having this effect, see Malm and Carton, *Overshoot*, 193; and for the politics of the problem, the excellent J. Mohorcich, ‘What Level of Resistance to Air Pollution Is Justified? On Violence and Self-Defense’, *Environment and Planning C: Politics and Space* (2023) 41: 583–99.

92 Tianle Yuan, Hua Song, Robert Wood et al., ‘Global Reduction in Ship-Tracks from Sulfur Regulations for Shipping Fuel’, *Science Advances* (2022) 8: 1–8.

93 Michael S. Diamond, ‘Detection of Large-Scale Cloud Microphysical Changes within a Major Shipping Corridor after Implementation of the International Maritime Organization 2020 Fuel Sulfur Regulations’, *Atmospheric Chemistry and Physics* (2023) 23: 8259–69; Hansen et al., ‘Global Warming’, 21. Cf. Paul Voosen, ‘“We’re Changing the Clouds”: An Unintended Test of Geoengineering Is Fueling Record Ocean Warmth’, *Science*, 2 August 2023.

94 Tianle Yuan, Hua Song, Lazaros Oreopoulos et al., ‘Abrupt Reduction in Shipping Emission as an Inadvertent Geoengineering Termination Shock Produces Substantial Radiative Warming’, *Communications Earth and Environment* (2024) 5: 1–8. This paper was reported in Damian Carrington, ‘“Termination Shock”: Cut in Ship Pollution Sparked Global Heating Spurt’, *Guardian*, 30 May 2024. Another study published around the same time hinted at the potentially haphazard and unexpected repercussions of the proto-shock: it drew a direct causal link between the drop in sulphur (and other) pollution in mainland China and an unusually warm spot of ocean in the Northeast Pacific. Hai Wang, Xiao-Tong Zheng, Wenju Ca et al., ‘Atmosphere Teleconnections from Abatement of China Aerosol Emissions Exacerbate Northeast Pacific Warm Blob Events’, *PNAS* (2024) 121: 1–10.

95 Compelling data against the hypothesis were presented in Helge F. Goessling, Thomas Rackow and Thomas Jung, 'Recent Global Temperature Surge Intensified by Record-Low Planetary Albedo', *Science* (2025) 387: 1–6. This study suggested that the surge in heating did not in fact correspond to the reduction in aerosols; rather, it was feedback from clouds that cut the earth's albedo – feedback from the warming itself, thus bound to get worse.

96 As pointed out in David Gelles, 'Less Pollution, More Global Warming', *New York Times*, 3 November 2023. Coal being both the main source of air pollution and the most climate-destructive fossil fuel, a general cut in coal consumption – in China and India in particular – would be the way to go. But fossil fuels could be cut out from shipping too: see Malm and Carton, *Overshoot*, 185–6. Note, however, that not even the most instant and complete eradication of shipping emissions in the early 2020s would have caused any immediate cooling, commensurate to the immediate warming from the reduction in aerosol pollution.

97 Baum et al., 'Double Catastrophe'.

98 Tang and Kemp, 'A Fate Worse', 7.

99 Lee Phillips, *Austerity Ecology and the Collapse-Porn Addicts: A Defence of Growth, Progress, Industry and Stuff* (Winchester: Zero, 2015). Other stories in the same genre have been told: AI-governed geoengineering spins out of control and crashes. Or a speculative bubble of cooling credits á la Make Sunsets causes an overcooling of Earth that eventually pops and turns into its opposite. Or thawing permafrost releases a virus that spreads across the globe in the form of a lethal pandemic; as part of the panicked response, aerosol injections target the highest latitudes to keep the ground frozen and set off an overcooling of the north with such chaotic side effects that it has to be switched off. McLaren, '"It's Not the Climate"', 262.

100 Douglas G. MacMartin, Peter J. Irvine, Ben Kravitz and Joshua B. Horton, 'Technical Characteristics of a Solar Geoengineering Deployment and Implications for Governance', *Climate Policy* (2019) 19: 1332. Or, as recognised in an earlier paper by the progenitor of the overshoot concept: one can imagine 'how rapidly the aerosol-induced cooling disappears once the injection of material into the stratosphere stops, as might become necessary should unexpected environmental damages arise'. T. M. L. Wigley, 'A Combined Mitigation/Geoengineering Approach to Climate Stabilization', *Science* (2006) 314: 452.

101 Researchers in 2020 uncovered a new extreme twist on this scenario. If emissions were to incessantly rise in a geoengineered world and the CO_2 concentration hit as high as 1,700 ppm, the whole operation would come undone, even if actual temperatures on Earth had not risen at all in the interim. This is because, at such elevated concentrations, the molecules of carbon dioxide break up stratocumulus clouds – rounded, wavey swathes of clouds that cool the earth – not gradually, but suddenly. Instant heating of five degrees would ensue. From this shock – a late result of the law of the tendency of side effects to rise – geoengineering would be unlikely to survive, and so the termination shock would add another few degrees, the planet doubly fried in a geological split second. Tapio Schneider, Colleen M. Kaul and Kyle G. Pressel, 'Solar Geoengineering May Not Prevent Strong Warming from Direct Effects of CO_2 on Stratocumulus Cloud Cover', *PNAS* (2020) 117: 30179–85.

102 Cf. Tang and Kemp, 'A Fate Worse', 7–9.

103 Stephenson, *Termination Shock*, 600–5, 630–91.

104 Gaskill Jr. and Charles E. Reese, 'Global Warming', 4.

105 Baum et al., 'Between the Sun', 4, 12; Szapudi, 'Solar Radiation', 3; Angel, 'Feasibility of Cooling', 17188–9; Fuglesang and García de Herreros Miciano, 'Realistic Sunshade',

277; Bromley et al., ‘Dust as a Solar’, 19.

106 Baum et al., ‘Between the Sun’, 6, 8, 11–12.

16. The Antinomies of Dimming the Sun

1 The White House, ‘Restoring the Quality of Our Environment. Report of The Environmental Pollution Panel President’s Science Advisory Committee’, November 1965, 127.

2 See for example, David W. Keith, ‘Geoengineering the Climate: History and Prospect’, *Annual Review of Energy and the Environment* 25 (2000): 262; Jonathan D. Oldfield and Marianna Poberezhskaya, ‘Soviet and Russian Perspectives on Geoengineering and Climate Management’, *WIREs Climate Change* (2023) 14: 4–7. On the Soviet prehistory of geoengineering, cf. Jonathan D. Oldfield, ‘Climate Modification and Climate Change Debates among Soviet Physical Geographers, 1940s–1960s’, *WIREs Climate Change* (2013) 4: 513–24. This theme in the environmental history of the Stalinist state deserves special treatment but is omitted here.

3 Oldfield and Poberezhskaya, ‘Soviet and Russian’, 6.

4 W. W. Kellogg and S. H. Schneider, ‘Climate Stabilization: For Better or for Worse?’, *Science* (1974) 186: 1167, 1170. In the light of caveats and uncertainties, however, the article counselled caution and further research before advocacy or deployment of stratospheric aerosol injections or any other technology for ‘climate stabilisation’. With thanks to Leah Aranowsky, who alerted us to this article. Note that one of the authors was the same Schneider who advocated adaptation as a ‘genesis strategy’ to substitute for mitigation.

5 For the details, see Muffett and Feit, ‘Fuel to the Fire’, 11–12.

6 Ibid., 37.

7 S. S. Penner, A. M. Schneider and E. M. Kennedy, ‘Active Measures for Reducing the Global Climatic Impacts of Escalating CO_2 Concentrations’, *Acta Astronomica* (1984) 11: 345, 348. Penner and colleagues argued that maximum acceptable cost for dealing with the climate problem would be one tenth of the ‘world-wide value of fossil-fuel systems’; particle injection sufficient to offset any warming could easily be bought at this price. Ibid., 345. The argument was restated in S. S. Penner and J. Haraden, ‘A Low-Cost Technology for Increasing the Earth’s Albedo to Mitigate Temperature Rises’, *Energy* (1993) 18: 1087–90.

8 Again suggesting simultaneous invention, Nordhaus mentioned (with no reference to Budyko) ‘using stratospheric dust to cool the earth’ as one option in his first paper on climate: Nordhaus, ‘Can We Control’, 8.

9 Nordhaus, ‘Economic Approaches’, 52.

10 William Nordhaus, ‘An Optimal Transition Path for Controlling Greenhouse Gases’, *Science* (1992) 258: 1317–18.

11 National Academy of Sciences, *Policy Implications of Greenhouse Warming: Mitigation, Adaptation, and the Science Base* (Washington, DC: National Academies Press, 1992), 60, 81.

12 Jeff Goodell, *How to Cool*, 122.

13 Ibid., 72. Incidentally, Teller was also one of the first scientists in the US to have warned about climate change, this already in 1957. He saw it as a reason to ‘supplement’ fossil fuels with his own preferred energy source of choice: nuclear fusion. See Edward Teller, ‘Energy Patterns of the Future’, in Allen Navis, Robert G. Dunlop, Edward Teller et al. (eds), *Energy and Man, a Symposium* (Appleton-Century-Crofts, New York, 1959), 55, 58.

14 Ibid., 70–87.
15 E. Teller, L. Wood and R. Hyde, ‘Global Warming and Ice Ages: I. Prospects for Physics-Based Modulation of Global Change’, working paper, Lawrence Livermore National Laboratory, 15 August 1997, quotation from 18.
16 Edward Teller, Roderick Hyde and Lowell Wood, ‘Active Climate Stabilization: Practical Physics-Based Approaches to Prevention of Climate Change’, working paper, Lawrence Livermore National Laboratory, 18 April 2002, 8.
17 Quoted in James Fleming, ‘The Climate Engineers’, *The Wilson Quarterly* (2007) 31: 48. For the pessimism about mitigation, see also Fred C. Iklé and Lowell Wood, ‘Climatic Engineering’, *The National Interest* (2008) no. 93: 18–24.
18 Quoted in Jeff Goodell, ‘Can Dr. Evil Save The World?’, *Rolling Stone*, 3 November 2006.
19 Goodell, *How to Cool the Planet*, 124–25.
20 David W. Keith and Hadi Dowlatabadi, ‘A Serious Look at Geoengineering’, *EOS: Transactions of the American Geophysical Union* (1992) 73: 289. On Keith and Wood, see Goodell, *How to Cool*, 123; Caldeira and Bala, ‘Reflecting on 50’, 11. On Keith’s substitutionism in the 1990s, see further Muffett and Feit, ‘Fuel to the Fire’, 38, 41. The same position was held by Wigley, the overshoot inventor: see Malm and Carton, *Overshoot*, 64–5, 93.
21 Keith, ‘Geoengineering the Climate’, 272–3.
22 Barrett, ‘The Incredible Economics’, 46.
23 David Rotman, ‘A Cheap and Easy Plan to Stop Global Warming’, *MIT Technology Review*, 8 February 2013.
24 Andrew C. Revkin, ‘Branson on the Power of Biofuels and Elders’, *New York Times*, 15 October 2009.
25 See Muffett and Feit, ‘Fuel to the Fire’, 44–5. We must then revise, or at least temper, the harsh dismissal of the ‘vulgar Marxist’ understanding of geoengineering in Andreas Malm, ‘The Future Is the Termination Shock: On the Antinomies and Psychopathologies of Geoengineering. Part One’, *Historical Materialism* (2022) 30: 5–6.
26 The year 2013 is quite appropriately identified as a turning point in Keith and Irvine, ‘Solar Geoengineering’, 550.
27 Raymond Pierrehumbert quoted in Berwyn, ‘60 Scientists’.
28 On this demographic bias and its implications, see, for example, Frank Biermann and Ina Möller, ‘Rich Man’s Solution? Climate Engineering Discourses and the Marginalization of the Global South’, *International Environmental Agreements* (2019) 19: 151–67; Jennie C. Stephens and Kevin Surprise, ‘The Hidden Injustices of Advancing Solar Geoengineering Research’, *Global Sustainability* (2020) 3: 1–6; Tina Sikka, ‘An Intersectional Analysis of Geoengineering: Overlapping Oppressions and the Demand for Ecological Citizenship’, in Sapinski et al., *Has It*, 99–118. The problem is recognised in NASEM, *Reflecting Sunlight*, 37. See further below.
29 David Keith, *A Case for Climate Engineering* (Cambridge: MIT Press, 2013), 15 (see further for example, 38); Keith and Irvine, ‘Solar Geoengineering’, 549; Belaia et al., ‘Optimal Climate’, 17. For similar statements, see, for example, Douglas G. MacMartin, Katharine L. Ricke and David W. Keith, ‘Solar Geoengineering as Part of an Overall Strategy for Meeting the 1.5°C Paris Target’, *Philosophical Transactions of the Royal Society A* (2018) 376: 2; Smith, ‘The Cost of Stratospheric’, 2; Felgenhauer et al., ‘Solar Geoengineering’, 7; Janos Pasztor [of Stardust], ‘Solar Geoengineering Research Needs Formal Global Debate’, *Nature* (2021) 595: 494; Wake Smith and Claire Henly, ‘Updated and Outdated Reservations about Research into Stratospheric Aerosol Injection’, *Climatic Change* (2021) 163: 8. The argument for complementarity was

present in some of the early seminal papers, which could be read as marking the transition away from substitutionism to something more respectable: for example, Crutzen, 'Albedo Enhancement', 216–17; Wigley, 'A Combined Mitigation/Geoengineering', 452.

30 Wagner, *Geoengineering*, 7; see further 28–9, 74, 99.

31 For example, Reynolds et al., 'Five Solar', 563; Belaia et al., 'Optimal Climate', 18.

32 For example, Buck and Nicholson, 'Solar Geoengineering', 1652–3.

33 Buck et al., 'Pandemic Politics', 3. Cf. for example, Bala et al., 'One Atmosphere', 8.

34 Cf. Catriona McKinnon, 'The Panglossian Politics of the Geoclique', *Critical Review of International Social and Political Philosophy* (2020) 23: 592.

35 David Keith and Douglas G. MacMartin, 'A Temporary, Moderate and Responsive Scenario for Solar Geoengineering', *Nature Climate Change* (2015) 5: 201–6.

36 Peter J. Irvine, Kerry Emanuel, Jie He et al., 'Halving Warming with Idealized Solar Geoengineering Moderates Key Climate Hazards', *Nature Climate Change* (2019) 9: 295–9; Irvine and Keith, 'Halving Warming'.

37 Keith and MacMartin, 'A Temporary, Moderate', 204–5.

38 Michael C. MacCracken, 'On the Possible Use of Geoengineering to Moderate Specific Climate Change Impacts', *Environmental Research Letters* (2009) 4: 11.

39 Wagner, *Geoengineering*, 40.

40 Although one could also read the work of Holly Jean Buck – *After Geoengineering* alongside *Ending Fossil Fuels* – as a similar story.

41 Made more harmless still by Robinson downplaying side effects and termination shock as such.

42 There is one exception. Jesse Reynolds has a proposal for how to ensure that deploying states also cut their emissions: trust them to avoid 'reputational damage'. Jesse Reynolds, 'Linking Solar Geoengineering and Emissions Reductions: Strategically Resolving an International Climate Change Policy Dilemma', *Climate Policy* (2022) 3: 293. If they do not live up to their mitigation duty, they will discredit themselves in the eyes of the world, and so they will be conscientious about that duty. This proposal has the merit of, at the very least, addressing the question of how to ensure that mitigation happens alongside geoengineering. What the answer amounts to, however, is precisely to trust in the goodness of states. 'In the linkage [between geoengineering and emissions reductions] which I believe has the greatest potential, one or more states would proclaim their right to deploy solar geoengineering if and only if they meet their own mitigation goals and the rest of the world insufficiently mitigates, and would promise to forego deployment if either condition is not met.' Ibid., 285. So, the linkage – the ideal combination – would be upheld through the scrupulous crackdown on emissions, undertaken by a state so devoted to that crusade and so honourable in character that it would give up its other project – geoengineering – if it could be seen to fail. This is an ethics more reminiscent of Arthurian romance than twenty-first-century climate politics as we know it.

43 For example, David W. Keith and Wake Smith, 'Solar Geoengineering Could Start Soon if It Starts Small', *MIT Technology Review*, 5 February 2024; Horton, 'The Emergency Framing', 150–1; Keith and MacMartin, 'A Temporary, Moderate', 205; MacMartin et al., 'Technical Characteristics', 1330; Pflüger et al., 'Flawed Emergency', 6; Smith, *Pandora's Toolbox*, 222, 275.

44 Cf. Rabitz, 'Going Rogue?', 105; Lenton, 'Can Emergency', 45; and the recognition of this as the likely scenario in Smith, *Pandora's Toolbox*, 277, 310. See further for example, J. G. Shepherd, 'Geoengineering the Climate: An Overview and Update', *Philosophical Transactions of the Royal Society A* (2012) 370: 4171.

45 Astrid Dannenberg and Sonja Zitzelsberger, ‘Climate Experts’ Views on Geoengineering Depend on their Beliefs about Climate Change Impacts’, *Nature Climate Change* (2019) 9: 771.

46 As rationalist-optimists themselves have recognised, in more formulaic language: ‘The benefits of SRM first increase, then saturate and decline’; or, the benefits ‘increase more slowly than linear, with the highest marginal benefit accruing initially’; or, the benefits ‘have a concave function’. Keith and MacMartin, ‘A Temporary, Moderate’, 203–4.

47 Even though this success might be bought at the cost of an initiation shock.

48 Cf. Christian Baatz, ‘Can We Have It Both Ways? On Potential Trade-Offs Between Mitigation and Solar Radiation Management’, *Environmental Values* (2016) 25: 42–3. One paper has contended that the eruption of Mt. Pinatubo in fact caused only a cooling of 0.2°C, rather than the 0.5°C of conventional wisdom: Boretti, ‘Reassessing the Cooling’. ‘If the cooling attributed to the Mt. Pinatubo eruption is overrated, then the impact of sulphate aerosols on cooling is overrated’ – i.e. geoengineering perhaps wouldn’t work as well as thought. Ibid., 2. Or it would simply need larger amounts of sulphate to accomplish the desired temperature drops (and thereby speed up the undesired side effects).

49 Cf. Ricke and Harding, ‘How May’, 832, 837–8.

50 As for a hypothetical third, non-climatic reason – the superior profitability of non-fossil energy sources – this should not ever be counted upon: see Malm and Carton, *Overshoot*.

51 Cf. Frederike Neuber and Konrat Ott, ‘The Buying Time Argument within the Solar Radiation Management Discourse’, *Applied Sciences* (2020) 10: 2, 4; Baatz, ‘Can We’, 36–7, 41.

52 Keith and Irvine, ‘Solar Geoengineering’, 551. Emphasis in original.

53 This contradiction is identified and formulated in slightly different terms in Neuber and Ott, ‘The Buying Time’, 6.

54 Quoted in Simons, ‘Startups Want’.

55 Wagner, *Geoengineering*, 11. Cf. Jesse Reynolds, ‘A Critical Examination of the Climate Engineering Moral Hazard and Risk Compensation Concern’, *The Anthropocene Review* (2015) 2: 181.

56 The effects of such failure are subject to extensive quantification in Sussane Baur, Alexander Nauels, Zebedee Nicholls et al., ‘The Deployment Length of Solar Radiation Modification: An Interplay of Mitigation, Net-Negative Emissions and Climate Uncertainty’, *Earth System Dynamics* (2023) 14: 367–81. The lock-in of geoengineering has been widely discussed, often as a potential result of the research itself: see for example, Rose C. Cairns, ‘Climate Geoengineering: Issues of Path-Dependence and Socio-Technical Lock-In’, *WIREs Climate Change* (2014) 5: 649–61; Catriona McKinnon, ‘Sleepwalking into Lock-In? Avoiding Wrongs to Future People in the Governance of Solar Radiation Management Research’, *Environmental Politics* (2019) 28: 441–59; Albert C. Lin, ‘Avoiding Lock-In of Solar Geoengineering’, *The Northern Kentucky Law Review* (2020) 47: 139–54. Geoengineering would here repeat the original lock-in of carbon, as theorised most classically in Gregory C. Unruh, ‘Understanding Carbon Lock-In’, *Energy Policy* (2000) 28: 817–30.

57 Boucher et al., ‘Implications of Delayed’.

58 This latter scenario is the one known as RCP8.5; the former is RCP2.6. Douglas G. MacMartin, Ken Caldeira and David W. Keith 2014, ‘Solar Geoengineering to Limit the Rate of Temperature Change’, *Philosophical Transactions of the Royal Society A*, 372: 1–13. The authors of this paper try to make it seem like 800 years would fall within the realm of ‘temporary’ geoengineering. But they do eventually admit that such ‘time

horizons are still long in comparison with most policy commitments' – an understatement if ever there was one. Ibid., 11. (And the underlying assumption here being that nearly a millennium of future time can be subsumed under the controlling forces of models, so much coming human history ready to conform to how scientists in the present want it to be.) On actual emissions tracking RCP8.5, see for example, Christopher R. Schwalm, Spencer Glendon and Philip B. Duffy, 'RCP8.5 Tracks Cumulative CO_2 Emissions', *Proceedings of the National Academies of Science* (2020) 117: 19656–7.

59 See Baur et al., 'The Deployment Length'.

60 Pierrehumbert, 'There Is No', 218.

61 Brovkin et al., 'Geoengineering Climate', 255. Cf. for example, Cairns, 'Climate Geoengineering', 651.

62 Cf. Benjamin K. Sovacool, Chad M. Baum, Roberto Cantoni and Sean Low, 'Actors, Legitimacy, and Governance Challenges Facing Negative Emissions Technologies and Solar Geoengineering Technologies', *Environmental Politics* (2024) 33: 349.

63 Stephen Robert Miller, 'Inside Silicon Valley's Grand Ambitions to Control Our Planet's Thermostat', *Noema Magazine*, 8 August 2024; Transparency International, 'Climate Geoengineering Technologies: Corruption and Integrity Gaps', 3 June 2022, 4–5.

64 Kevin Surprise, Duncan McLaren, Ina Möller et al., 'Profit-Seeking Solar Geoengineering Exemplifies Broader Risks of Market-Based Climate Governance', *Earth System Governance* (2025), online first.

65 Kate Brown, 'Chernobyl's Disastrous Cover-Up Is a Warning for the Next Nuclear Age', *Guardian*, 4 April 2019.

66 Ibid.

67 Oldfield and Poberezhskaya, 'Soviet and Russian', 8–10.

68 Yu. A. Izrael, E. M. Volodin, S. V. Kostrykin et al., 'The Ability of Stratospheric Climate Engineering in Stabilizing Global Mean Temperatures and an Assessment of Possible Side Effects', *Atmospheric Science Letters* (2014) 15: 140.

69 Quoted in Ehren Helmut Pflugfelder, *Geoengineering, Persuasion and the Climate Crisis: A Geologic Rhetoric* (Tuscaloosa, University of Alabama Press, 2023), 63.

70 *CNN*, 'The Russian Didn't Bark', 16 October 2003.

71 Fleming, *Fixing the Sky*, 254–5; Fleming, 'The Climate Engineers', 49.

72 Oldfield and Poberezhskaya, 'Soviet and Russian', 10.

73 Jason J. Blackstock, David S. Battisti, Ken Caldeira et al., 'Climate Engineering Responses to Climate Emergencies', Novim, 29 July 2009; cf. Muffett and Feith, 'Fuel to the Fire', 44.

74 Steven E. Koonin, *Unsettled: What Climate Science Tells Us, What It Doesn't, and Why It Matters* (Dallas, TX: BenBella, 2021), 239. Further: 'Many analyses suggest that a warming of less than 2°C is likely to have a small net positive economic impact, thanks to improved agricultural conditions and reduced heating costs in the temperate northern latitudes.' Ibid.

75 Ibid., 210.

76 Ibid., 242.

77 NASEM, *Reflecting Sunlight*, xi. 'The starting point for the committee is that SG [solar geoengineering] is not a substitute for mitigation, nor does it lessen the urgency for pushing mitigation actions.' Ibid., 25. See further for example, 27, 256. 'There is no substitute for aggressive cuts in greenhouse-gas emissions. But the risks and benefits of technologies that could mitigate' – Freudian slip – 'global warming need to be evaluated', *Nature* opened its editorial commending the NASEM report. *Nature* 2021, 'Give Research into Solar Geoengineering a Chance', 593: 167.

78 One form in which we have already encountered this problem is that of the ‘residual emissions’ conundrum discussed above.

79 Keith and MacMartin, ‘A Temporary, Moderate’, 205. In their self-pity paper from the end of the 2010s, the rationalist-optimists deplored – probably with reference to the events of 2018–19 – that climate disasters had so far piqued public interest in mitigation rather than geoengineering. Felgenhauer et al., ‘Solar Geoengineering’, 11–12. They were, in other words, jealous of the attention the former had received.

80 Wagner, *Geoengineering*, 99.

81 Reynolds, ‘A Critical Examination’, 180. Or: comparing the cost of mitigation with that of geoengineering is ‘relevant because the comparison is to other means of achieving the same result.’ Keith et al., ‘Solar Geoengineering Reduces’, 618. For similar arguments, see Oliver Morton, *The Planet Remade: How Geoengineering Could Change the World* (London: Granta, 2015), 160; Mohammad M. Khabbazan, Marius Stankoweit, Elnaz Roshan et al., ‘How Can Solar Geoengineering and Mitigation Be Combined under Climate Targets?’, *Earth System Dynamics* (2021) 12: 1539; Wagner, *Geoengineering*, 59; Belaia et al., ‘Optimal Climate’, 18.

82 Reynolds, ‘Is Solar’, 3.

83 Jesse Reynolds, *Solar Geoengineering: Managing Climate Change in the Anthropocene* (Cambridge: Cambridge University Press, 2019), 45; Jesse Reynolds, ‘Linking Solar Geoengineering and Emissions Reductions: Strategically Resolving an International Climate Change Policy Dilemma’, *Climate Policy* (2022) 3: 297.

84 Keith, *A Case*, 143–4.

85 Gernot Wagner and Martin L. Weitzman, *Climate Shock: The Economic Consequences of a Hotter Planet* (Princeton: Princeton University Press, 2016), 151.

86 And if there is, that value will be ‘outweighed by the reduction in climate change by solar geoengineering’. Reynolds, *Solar Geoengineering*, 41.

87 Keith, *A Case*, 29, 31.

88 Edward A. Parson and Lia N. Ernst, ‘International Governance of Climate Engineering’, *Theoretical Inquiries in Law* (2013) 14: 318.

89 Cf. Konrad K. Ott, ‘On the Political Economy of Solar Radiation Management’, *Frontiers in Environmental Science* (2018) 6: 5–6; Kevin Surprise, ‘Gramsci in the Stratosphere: Solar Geoengineering and Capitalist Hegemony’, in Sapinski et al., *Has It Come*, 190, 197–8.

90 Which was never, as we have seen, very solid even then. (Note that there are no clear-cut chronological distinctions between these three moments.)

91 Reynolds, *Solar Geoengineering*, 222 (cf. for example, 45, 53); Wagner, *Geoengineering*, 73 (cf. for example, 82–3). And cf. Keith, ‘Geoengineering the Climate’, 277.

92 Keith, ‘Geoengineering the Climate’, 276; on this as the first use of the term and its significance more generally, see Andrew Lockley and D’Maris Coffman, ‘Distinguishing Morale Hazard from Moral Hazard in Geoengineering’, *Environmental Law Review* (2016) 18: 194–204; on its use in economics, Cédric Durand, *Fictitious Capital: How Finance Is Appropriating Our Future* (London: Verso, 2017 [2014]), 15, 37.

93 The term began to spread after Duncan McLaren, ‘Mitigation Deterrence and the “Moral Hazard” of Solar Radiation Management’, *Earth’s Future* (2016) 4: 596–602; see further references in note 3 on page 523.

94 For this argument in the context of geoengineering, see for example, Ricke and Harding, ‘How May’, 829; in that of removal, R. M. Colvin, L. Kemp, A. Talberg et al.,

‘Learning from the Climate Change Debate to Avoid Polarisation on Negative Emissions’, *Environmental Communication* 14 (2020): 26.

95 Christine Merk, Gert Pönitzsch and Katrin Rehdanz, ‘Knowledge about Aerosol Injection Does Not Reduce Individual Mitigation Efforts’, *Environmental Research Letters* (2016) 11: 1–6.

96 Todd L. Cherry, Steffen Kallbekken, Stephan Kroll and David M. McEvoy, ‘Does Solar Geoengineering Crowd Out Climate Change Mitigation Efforts? Evidence from a Stated Preference Referendum on a Carbon Tax’, *Climatic Change* (2021) 165: 1–8.

97 Sarah Polborn and Felix Tintelnot, ‘How Geoengineering May Encourage Carbon Dioxide Abatement’, Center for Research on International Financial and Energy Security, Penn State University, 2009; Dan M. Kahan, Hank Jenkins-Smith, Tor Tarantola et al., ‘Geoengineering and Climate Change Polarization: Testing a Two-Channel Model of Science Communication’, *The Annals of the American Academy of Political and Social Science* (2015) 658: 192–222; and for game theory, Adrien Fabre and Gernot Wagner, ‘Availability of Risky Geoengineering Can Make an Ambitious Climate Mitigation Agreement More Likely’, *Humanities and Social Sciences Communications* (2020) 7: 1–4, repeated in Wagner, *Geoengineering*, 29–34. Further problems with these studies are highlighted by Smith, *Pandora’s Toolbox*, 310–11. A later game-theoretical paper in support of the inverse hypothesis is Todd L. Cherry, Stephan Kroll, David M. McEvoy et al., ‘Climate Cooperation in the Shadow of Solar Geoengineering: An Experimental Investigation of the Moral Hazard Conjecture’, *Environmental Politics* (2023) 32: 362–70. One study reports neither a moral hazard nor an inverse moral hazard, a non-result interpreted as disproving the former: Philipp Schoenegger and Kian Mintz-Woo, ‘Moral Hazards and Solar Radiation Management: Evidence from a Large-Scale Online Experiment’, *Journal of Environmental Psychology* (2024) 95: 1–11.

98 Reynolds, ‘Is Solar’, 3.

99 Wagner, *Geoengineering*, 144, 140. Cf. 69, 130; Fabre and Wagner, ‘Availability of Risky’, 3; Wagner and Zizzamia, ‘Green Moral’, 275; Reynolds, ‘Linking Solar’, 287, 295.

100 Keith, *A Case*, 110.

101 Sebastian D. Eastham, Debra K. Weisenstein, David W. Keith and Steven R. H. Barrett, ‘Quantifying the Impact of Sulfate Geoengineering on Mortality from Air Quality and UV-B Exposure’, *Atmospheric Environment* (2018) 187: 424–34.

102 Wagner, *Geoengineering*, for example, 36–60, 71, 145. The same quest is endorsed by another fan of the inverse moral hazard: Reynolds, *Solar Geoengineering*, 201.

103 On the role of this attribute in the modelling, see Duncan McLaren and Olaf Corry, ‘Clash of Geofutures and the Remaking of Planetary Order: Faultlines Underlying Conflicts over Geoengineering Governance’, *Global Policy* (2021) 12: 23, 25, 30; Duncan McLaren, ‘“It’s Not the Climate, Stupid”: Exploring Nonideal Scenarios for Solar Geoengineering Development’, *Ethics and International Affairs* (2024) 38: 256–7, 260–1.

104 Reynolds, *Solar Geoengineering*, 67; see further for example, 5–6, 54, 68–9.

105 Reynolds, ‘A Critical Examination’, 186, 179. Emphasis added. For more similar assumptions, see for example, Keith and Irvine, ‘Solar Geoengineering’, 551; Rabitz, ‘Governing the Termination’, 506; Reynolds, ‘Linking Solar’, 290.

106 Smith, ‘The Cost of Stratospheric’, 5.

107 Smith and Wagner, ‘Stratospheric Aerosol’, 9. Cf. Smith, *Pandora’s Toolbox*, 245.

108 Belaia et al., ‘Optimal Climate’, 18.

109 Here following the excellent critique developed by McKinnon, ‘The Panglossian Politics’, 586.

110 MacMartin et al., ‘Technical Characteristics’, 1328–32. Cf. MacMartin et al., ‘Solar Geoengineering’, 2–3; Keith and MacMartin, ‘A Temporary, Moderate’, 204. In the case of a volcano eruption, the injection would also have to increase in the opposite hemisphere, so as to avoid the overloading of sulphur in one hemisphere – an imbalance that can upset precipitation patterns. Tang and Kemp, ‘A Fate Worse’, 6. On the intricacies of an eruption in a geoengineered world, see further A. Laakso, H. Kokkola, A.-I. Partanen et al., ‘Radiative and Climate Impacts of a Large Volcanic Eruption during Stratospheric Sulfur Geoengineering’, *Atmospheric Chemistry and Physics* (2016) 16: 305–23.

111 Kravitz et al., ‘Comparing Surface’; Daniele Visioni, Douglas G. MacMartin, Ben Kravitz et al., ‘Seasonally Modulated Stratospheric Aerosol Geoengineering Alters the Climate Outcomes’, *Geophysical Research Letters* (2020) 47: 1–10. Or time the injections in the Arctic to the spring, when they have the greatest effect: Walker Raymond Lee, Douglas G. MacMartin, Daniele Visioni and Ben Kravitz, ‘High-Latitude Stratospheric Aerosol Geoengineering Can Be More Effective If Injection Is Limited to Spring’, *Geophysical Research Letters* (2021) 48: 1–11.

112 For instance, concentrated injections to cool the Arctic and save it from regional tipping points would throw the Intertropical Convergence Zone completely off track. Smith et al., ‘On Thin Ice’; Smith et al., ‘A Subpolar-Focused’; Moore et al., ‘Reduced Ice Loss’, 15–16; Duffey et al., ‘Solar Geoengineering’, 13, 16; Roose et al., ‘Quantification of Tropical’, 4254. Injections would thus have to be globally symmetrical. Put differently, any attempt to make geoengineering interventions surgically precise so as to save this or that subsystem would have repercussions on other subsystems.

113 Z. Dai, D. K. Weisenstein and D. W. Keith, ‘Tailoring Meridional and Seasonal Radiative Forcing by Sulfate Aerosol Solar Geoengineering’, *Geophysical Research Letters* (2018) 45: 1030.

114 Ben Kravitz, Douglas G. MacMartin, Hailong Wang and Philip J. Rasch, ‘Geoengineering as a Design Problem’, *Earth System Dynamics* (2016) 7: 469–97; George A. Ban-Weiss and Ken Caldeira, ‘Geoengineering as an Optimization Problem’, *Environmental Research Letters* (2010) 5: 1–9; see further for example, Douglas G. MacMartin, David W. Keith, Ben Kravitz and Ken Caldeira, ‘Management of Trade-Offs in Geoengineering through Optimal Choice of Non-Uniform Radiative Forcing’, *Nature Climate Change* (2013) 3: 365–8; Smith, *Pandora’s Toolbox*, 232.

115 MacMartin et al., ‘Technical Characteristics’, 1328. For the general problem, cf. NASEM, *Reflecting Sunlight*, 69–71; Smith, *Pandora’s Toolbox*, 278.

116 Cf. NASEM, *Reflecting Sunlight*. 59, 64; Smith, *Pandora’s Toolbox*, 226.

117 Kravitz et al., ‘Comparing Surface’, 7913.

118 Long Cao, Lei Duan, Govindasamy Bala and Ken Caldeira, ‘Simultaneous Stabilization of Global Temperature and Precipitation through Cocktail Geoengineering’, *Geophysical Research Letters* (2017) 44: 7429–37. In a variation on the same theme, ‘the potential detrimental effects of SAG [stratospheric aerosol geoengineering] on agriculture could be compensated for by changes in fertilizer use.’ Kravitz and MacMartin, ‘Uncertainty and the Basis’, 69.

119 Hulme, *Can Science*, 92, 100–1.

120 Fleming, *Fixing the Sky*, 194; and for more on von Neumann, see 189–94.

121 This is because nature has irreducible autonomy and cannot be fully subsumed under any controlling subject or mechanical intelligence, however refined; some elements will always slip away and create further trouble in another part of the system – not because

of imperfect knowledge, whether in the phase of deployment or that of modelling, but precisely because of the intrinsic autonomy of nature: cf. Malm, *The Progress*.

122 For some reflections pointing in the direction of this argument, see Goodell, *How to Cool*, 40; Wagner, *Geoengineering*, 98.

123 Rabitz, 'Governing the Termination', 513.

124 Wagner, *Geoengineering*, 20, 99, 109, 113–14.

17. Towards a Freudo-Marxist Theory of Geoengineering

1 Key titles include Joseph Dodds, *Psychoanalysis and Ecology at the Edge of Chaos: Complexity Theory, Deleuze, Guattari and Psychoanalysis for a Climate in Crisis* (Hove: Routledge, 2011); Sally Weintrobe (ed.), *Engaging with Climate Change: Psychoanalytic and Interdisciplinary Perspectives* (Hove: Routledge, 2013); E. Ann Kaplan, *Climate Trauma: Foreseeing the Future in Dystopian Film and Fiction* (New Brunswick: Rutgers University Press, 2016); Donna M. Orange, *Climate Crisis, Psychoanalysis, and Radical Ethics* (Abingdon: Routledge, 2017); Lee Zimmerman, *Trauma and the Discourse of Climate Change: Literature, Psychoanalysis, and Denial* (London: Routledge, 2020); Sally Weintrobe, *Psychological Roots of the Climate Crisis: Neoliberal Exceptionalism and the Culture of Uncare* (New York: Bloomsbury, 2021); Tad DeLay, *Future of Denial: The Ideologies of Climate Change* (London: Verso, 2024); and, of course, although her debt to psychoanalysis (via Stanley Cohen) is not explicitly acknowledged, Kari Marie Norgaard, *Living in Denial: Climate Change, Emotions, and Everyday Life* (Cambridge MA: MIT Press, 2011). A poor contribution to the genre is Cosimo Schinaia, *Psychoanalysis and Ecology: The Unconscious and the Environment* (Abingdon: Routledge, 2022). A succinct survey of the research, with a focus on the problem of climate anxiety, is Joseph Dodds, 'The Psychology of Climate Anxiety', *BJPsych Bulletin* (2021) 45: 222–6.

2 Freud, *The Interpretation of Dreams*, 330 (emphasis in original); quoted in Zimmerman, *Trauma and the Discourse*, 126. Zimmerman rightly points out that Freud's own interpretation of the dream is of no use for the matter at hand, since it alludes neither to anxiety nor guilt nor any other possible mechanism of climate denial; caught within the paradigm of the dream as wish fulfilment, for Freud the meaningful core of the dream is simply that the child has come alive again. Freud, *The Interpretation of Dreams*. In fact, this interpretation is massively underwhelming, as Freud himself ascribes special importance to the dream of the burning child – a 'model dream', it has 'very special claims on our attention' – without extracting its significant material. Ibid., 330; cf. 359–60.

3 For example, Sally Weintrobe, 'The Difficult Problem of Anxiety in Thinking about Climate Change', in Weintrobe, *Engaging with Climate*, 36–8; Hoggett, 'Climate Change in a Perverse Culture', in ibid., 60–3; Orange, *Climate Crisis*, 19.

4 The most powerful study of these mechanisms remains, more than a decade later – rather a testimony to the *poverty* of this literature – Norgaard, *Living in Denial*.

5 Alenka Zupančič, *Disavowal* (Cambridge: Polity, 2024), 7–11.

6 Ibid., 2.

7 Sigmund Freud, *A Case of Hysteria (Dora)* (Oxford: Oxford University Press, 2013 [1905]), 54 (italics in original).

8 Cf. Mark Bould, *The Anthropocene Unconscious: Climate Catastrophe Culture* (London: Verso, 2021), for example, 15–17, 43, 132; Andreas Malm, '"This Is the Hell

That I Have Heard Of”: Some Dialectical Images in Fossil Fuel Fiction’, *Forum for Modern Language Studies* (2017) 53: 121–41.

9 Freud, *A Case*, 59 (emphasis in original). Inverting the element of fire into that of water, Freud insists on the latent content of the dream being Dora’s late bed-wetting, which in turn is proof of her masturbating as a child, which is related to her supposed desire to kiss Freud himself as well as to her venereal disease, and so on, in one of the more embarrassing episodes of early Freudianism.

10 Ibid., 55.

11 Note that the father and, originally, Dora herself too were fond of jewels, in her telling: ibid., 58. Siding with Dora against Freud, in the work of dream interpretation for the overshoot conjuncture, here means taking the material components of the dream seriously and literally. Nature dethrones sex as the master code of interpretation. Cf. Malm, ‘“This Is the Hell”’, 128–9. Such an argument would be in line with that sketched in Dominic Pettman, *Peak Libido: Sex, Ecology, and the Collapse of Desire* (Cambridge: Polity, 2021).

12 Weintrobe, *Psychological Roots*, 23, 18.

13 Adorno, *Negative Dialectics*, 363. ‘Their coldness is one of their most conspicuous traits: they are cold in the face of the suffering of others, but also towards themselves.’ Theodor Adorno, ‘The Problem of a New Type of Human Being’, in *Current of Music: Elements of a Radio Theory* (Cambridge: Polity, 2009), 466.

14 The Freudian phrase quoted in Stanley Cohen, *States of Denial: Knowing about Atrocities and Suffering* (Cambridge: Polity, 2001), 29; of dominant groups having this capacity, Cohen provides ample documentation in his classical work.

15 Henrike Kohpeiß, ‘Bourgeois Coldness: Affect and Colonial Subjectivity’, *Parallax* (2023) 29: 440, 430.

16 A phrase from W. E. B. Du Bois quoted in ibid., 440, 442.

17 Gabor Maté, ‘It’s Like We’re Watching Auschwitz on TikTok’, *Middle East Eye*, YouTube, 16 October 2024.

18 A very early comment on this advertisement was Raz Segal, ‘A Textbook Case of Genocide’, *Jewish Currents*, 13 October 2023. For rolling research coverage of the genocide, how amply it meets the criteria for that crime and how the intention to commit it has been expressed, see the premier *Journal of Genocide Research*. Among the highlights published as of this writing are Nimer Sultany, ‘A Threshold Crossed: On Genocidal Intent and the Duty to Prevent Genocide in Palestine’, *Journal of Genocide Research* (2024), online first; Orna Ben-Naftali, Eitan Diamond and Aner Shofty, ‘Esprit de Corpse: Genocide in the Shadowland of Gaza’, *Journal of Genocide Research* (2024), online first; Alonso Gurmendi Dunkelberg, ‘How to Hide a Genocide: Modern/Colonial International Law and the Construction of Impunity’, *Journal of Genocide Research* (2025), online first; Tamir Sorek, ‘Mainstreaming a Genocidal Imagination in Israeli Society: Settler-Colonialism, Settler Anxiety, and Biblical Cues’, *Journal of Genocidal Research* (2025), online first.

19 See further Andreas Malm, *The Destruction of Palestine Is the Destruction of the Earth* (London: Verso, 2025).

20 We must here omit the intrinsic links between fossil fuels and the occupation of Palestine. For these, see further, for example, ibid.; Adam Hanieh, ‘Framing Palestine, Israel, the Gulf States and American Power in the Middle East’, *Transnational Institute*, 13 June 2024; Zachary Cuyler, ‘Power Struggles: Energy as a Weapon of War, Domination and Resistance in Palestine’, *Middle East Report*, winter 2024; Lydia de Leeuw and Misa Norigami, ‘Fuelling the Flames in Gaza: Exploring the Legal Consequences for States and Corporations Involved in Supplying Jet Fuel to the Israeli

Military', SOMO: The Centre for Research on Multinational Corporations, May 2024; Lydia de Leeuw, Max Lamb and Misa Norigami, 'Powering Injustice: Exploring the Legal Consequences for States and Corporations Involved in Supplying Energy to Israel', SOMO: The Centre for Research on Multinational Corporations, December 2024; OilChange International, 'Behind the Barrel: New Insights into the Countries and Companies Behind Israel's Fuel Supply', August 2024.

21 Isabella Hammad, *Recognizing the Stranger: On Palestine and Narrative* (New York: Grove Atlantic, 2024), 75.

22 For some reflections pointing in this direction, see Paul Hoggett, 'Confronting the Inhuman', *Psychoanalytic Psychotherapy* (2024), online first. For some excellent reflections focusing strictly on Gaza and the occupation, see David Bell, 'Some Psychoanalytical Reflections on the Events in Gaza', *Psychoanalytic Psychotherapy* (2024) 38: 294–306.

23 Cf. Rob Fletcher, 'Beyond the End of the World: Breaking Attachments to a Dying Planet', in Ilan Kapoor (ed.), *Psychoanalysis and the Global* (Lincoln: University of Nebraska Press, 2018), 49, 63–4.

24 It now adorns the cover of Jean-Baptiste Fressoz, *Happy Apocalypse: A History of Technological Risk* (London: Verso, 2024) as well as Carl Cassegård and Håkan Thörn, *I apokalypsens skugga: Miljörörelser och industrikapitalism 1870–2020* (Göteborg: Daidalos, 2023).

25 Kelly Grovier, 'The Golfers Who Finished their Round While a Forest Burned', BBC, 8 September 2017.

26 Golf Talk Canada TV and Radio, 'Wildfire Doesn't Stop these Guys from Playing Golf', YouTube, 13 September 2017.

27 AFP, 'More than 1,000 Hajj Pilgrims Die Amid Temperatures Approaching 52C in Mecca', *Guardian*, 20 June 2024.

28 Suchul Kang, Jeremy S. Pal and Elfatih A. B. Eltahir, 'Future Heat Stress During Muslim Pilgrimage (Hajj) Projected to Exceed "Extreme Danger" Levels', *Geophysical Research Letters* (2019) 46: 10094–100; Saber Yezli, Salleh Ehaideb, Yara Yassin et al., 'Escalating Climate-Related Health Risks for Hajj Pilgrims to Mecca', *Journal of Travel Medicine* (2024) 31: 1–9.

29 Oliver Milman, 'Trump Vows to "Drill, Baby, Drill" Despite Rally Attendees Wilting in Extreme Heat', *Guardian*, 10 June 2024. On the turning up of the volume, see, for example, Oliver Milman and Dharna Noor, '"In a Word, Horrific": Trump's Extreme Anti-Environment Blueprint', *Guardian*, 6 February 2024; Michael Copley, 'A Second Trump Term Could Slow the Shift from Fossil Fuels as Climate Threats Grow', NPR, 25 June 2024; Nina Lakhani, 'Climate Advocates Fear Picking JD Vance for VP is "a Dangerous Step Backward"', *Guardian*, 16 July 2024; Marcus Baram, 'How J.D. Vance Went from Green Tech Investor to Climate Change Doubter', *Rolling Stone*, 20 July 2024.

30 Gloria Dickie, 'Trump Cuts Target World-Leading Greenhouse Gas Observatory in Hawaii', *Reuters*, 11 March 2025.

31 Orange, *Climate Crisis*, 80–1; cf. for example, 14; Hoggett, 'Climate Change', 57; Zupančič, *Disavowal*, 43–4.

32 Adorno, *Negative Dialectics*, 398.

33 On far-right denialism, see Malm and the Zetkin Collective, *White Skin*.

34 Here, again, following the typology of denial first developed in Cohen, *States of Denial* and applied to climate in Norgaard, *Living in Denial*.

35 Adorno, *Philosophical Elements*, 5; cf. 95.

36 Freud, 'New Introductory', 59.

37 Sigmund Freud, ‘Formulations on the Two Principles of Psychic Functioning’, in *The Unconscious* (London: Penguin, 2005 [1911]), 3; Sigmund Freud, ‘Neurosis and Psychosis’, in *The Standard Edition of the Complete Psychological Works of Sigmund Freud: Volume XIX* (London: Vintage, 2001 [1924]), 150. Cf. for example, Sigmund Freud, ‘The Loss of Reality in Neurosis and Psychosis’, in *The Standard Edition, Volume XIX* (London: Vintage, 2001 [1924]), for example, 183.

38 Freud, ‘Formulations’, 3 (emphasis added).

39 Weintrobe, *Psychological Roots*, 114. For the analysis of the 1980s, see for example, 65–71.

40 Sigmund Freud, ‘The Dissolution of the Oedipus Complex’, in *The Standard Edition, Volume XIX* (London: Vintage, 2001 [1924]), 177. Freud made uncountable revisions of his theories, but he never abandoned this hard core of his research programme: the porous or even non-existing border between the normal and the pathological. Two cases from the beginning and end of his career: ‘The psychical mechanism which the neurosis makes use of is not first created by a pathological disorder attacking the inner life, but is already present in the normal structure of the psychical apparatus.’ Freud, *The Interpretation of Dreams*, 401–2. ‘It is not scientifically feasible to draw a line of demarcation between what is psychically normal and abnormal; so that that distinction, in spite of its practical importance, possesses only a conventional value.’ Sigmund Freud, ‘An Outline of Psycho-Analysis’, in *The Standard Edition of the Complete Psychological Works of Sigmund Freud: Volume XXIII* (London: Vintage, 2001 [1940]), 195. This hard core has obvious validity for the study of bourgeois insanity, of which this present study has offered plenty of cases. It cannot be demarcated from bourgeois normality.

41 A common distinction is to reserve ‘denial’ for present material and ‘repression’ for past, but more common still is to treat them as essentially synonymous: see for example, Cohen, *States of Denial*, 118–19. The fullest up-to-date account and critical analysis of the Freudian theory of repression is Simon Boag, *Freudian Repression, the Unconscious, and the Dynamics of Inhibition* (London: Routledge, 2012). For shorter surveys, see Simon Boag, ‘Freudian Repression, the Common View, and Pathological Science’, *Review of General Psychology* (2006) 10: 74–86; Salman Akhtar, ‘Repression: A Critical Assessment and Update of Freud’s 1915 Paper’, *The American Journal of Psychoanalysis* (2020) 80: 241–58.

42 The classic account is Russell Jacoby, *The Repression of Psychoanalysis: Otto Fenichel and the Political Freudians* (Chicago: University of Chicago Press, 1983).

43 Jacobson is mentioned in passing exactly once in David Pavón-Cuéllar, *Marxism and Psychoanalysis: In or Against Psychology?* (Abingdon: Routledge, 2017), 127. She is given somewhat more attention as a member (and analyst) of the innovative Leninist group New Beginning and the sex-pol circle around Wilhelm Reich in Terence Renaud, *New Lefts: The Making of a Radical Tradition* (Princeton: Princeton University Press, 2021), 66–70, 80. For a report in English on her psychoanalytic work and prison writings, published in German in 2015, see Martina Kolb, ‘Poetic Agency: Edith Jacobson’s Captivity’, *Journal of the American Psychoanalytic Association* (2020) 68: 979–91.

44 Edith Jacobson, ‘Denial and Repression’, *Journal of the American Psychoanalytic Association* (1957) 5: 81, 75, 83.

45 According to an account inspired by Jacobson (and Robert Waelder): Frank Miller, ‘Denial: A Contribution to Psychoanalytic Theory’, *Journal of the American Academy of Psychoanalysis* (1977) 5: 187–93.

46 Sigmund Freud, ‘Repression’, in *The Standard Edition of the Complete Psychological Works of Sigmund Freud: Volume XIV* (London: Vintage, 2001 [1915]), 147 (emphasis in original). Cf. for example, Sigmund Freud, ‘Introductory Lectures on Psychoanalysis (Part III)’, in *The Standard Edition of the Complete Psychological Works of Sigmund Freud: Volume XVI* (London: Vintage, 2001 [1917]), 342.

47 Boag, *Freudian Repression*, for example, xiii, 5, 9, 28, 61, 193–8. Note, again, that repression can be both normal and pathological (because the two are never far apart). ‘This effortless and regular way the psychical process has of turning away from the memory of what was once painful offers us the model and the first example of *psychical repression*. It is widely recognised how much of this avoidance of what is painful – ostrich tactics – is still demonstrably to be found in the inner life of normal adults.’ Freud, *The Interpretation of Dreams*, 396 (emphasis in original). Because the unconscious is comprised of repressed material, repression is at the root of the very psychical apparatus as such: see for example, Sigmund Freud, ‘The Ego and the Id’, *The Standard Edition, Volume XVI* (London: Vintage, 2001 [1927]), 14–15, 24. Repression is active in the formation of the Oedipus complex, the superego, guilt, dreams, resistance and several other central – and decidedly normal – psychic phenomena.

48 Sigmund Freud, *Moses and Monotheism* (New York: Vintage, 1967 [1939]), 163.

49 Sigmund Freud, ‘The Neuro-Psychoses of Defence’, in *The Standard Edition of the Complete Psychological Works of Sigmund Freud: Volume III* (London: Vintage, 2001 [1894]), 91; Sigmund Freud, ‘Inhibitions, Symptoms and Anxiety’, in *The Standard Edition of the Complete Psychological Works of Sigmund Freud, Volume XX* (London: Vintage, 2001 [1926]), 92 (cf. 145, 153). Elsewhere, Freud, in the English translation, refers to the contradiction as an ‘incompatibility’, for example, Sigmund Freud, ‘Further Remarks on the Neuro-Psychoses of Defence’, in *The Standard Edition, Volume III* (London: Vintage, 2001 [1896]), 162.

50 Here using the alternative translation of the 1915 paper in Freud, ‘Repression’, in *The Unconscious*, 40. On psychic energy in this context, see Boag, *Freudian Repression*, 14–15.

51 Freud, ‘Repression’, in *The Unconscious*, 39; Sigmund Freud, ‘Obsessive Actions and Religious Practices’, in *The Standard Edition of the Complete Psychological Works of Sigmund Freud: Volume IX* (London: Vintage, 2001 [1907]), 124. Cf. for example, Freud, ‘Introductory Lectures’, 373; Freud, ‘New Introductory’, 68; Boag, *Freudian Repression*, 23, 53–4, 115–16.

52 Freud, ‘Introductory Lectures’, 350. Cf. for example, 259; Freud, *Moses and Monotheism*, 120–25, 164.

53 Freud, ‘Repression’, in *The Unconscious*, 37–8. Freud does not use the term ‘side effects’, of course, but speaks of the formation of ‘substitutes’ or simply ‘symptoms’, on which more below. See further, for example, 41–2; Sigmund Freud, *Civilization and Its Discontents* (London: Penguin, 2002 [1930]), 75; Boag, *Freudian Repression*, 13, 35, 55.

54 Freud, ‘Inhibitions, Symptoms’, 94; Boag, *Freudian Repression*, 55–6, 203.

55 Freud, ‘Inhibitions, Symptoms’, 113.

56 Freud, ‘Repression’, in *The Unconscious*, 42. Cf. Boag, *Freudian Repression*, 52.

57 Herbert Marcuse, *Five Lectures: Psychoanalysis, Politics, and Utopia* (Boston: Beacon, 1970), 26.

58 Furthermore, space beyond the stratosphere is not the unconscious of the earth. In line with Freud’s general topographic axis, the dangerous surplus energy is indeed repressed from above, but through a blockage directed towards the exterior source of energy from

which everything in the interior is derived: a loop that does not quite map onto anything in Freud.

59 Freud, 'Introductory Lectures', 295. Other versions of the censorship metaphor appear, of course, in Freud, *The Interpretation of Dreams*, 112–13, 344.

60 The problem is ably discussed in Boag, *Freudian Repression*, 145–66.

61 Ibid., 9, 20, 61–2. Renewed repression of side effects would count as 'auxiliary traumatic moments'. Ibid., 10.

62 Less immediately applicable is her distinction between denial targeting external reality and repression specialising in internal drives. This distinction is muddled in Freud too: he will sometimes say that repression is identical to running away from a dangerous external object; sometimes that 'the protective shield' of repression 'exists only in regard to external stimuli, not in regard to instinctual demands'; and sometimes other, even less clear-cut things about the external-internal boundary. Freud, 'Inhibitions, Symptoms', 92, 94; cf. for example, 145, 155–6. Far less ambiguous is the temporal, historical aspect of Jacobson's theory: denial as the precursor of repression.

63 William Shakespeare, *Macbeth* (Oxford: Oxford University Press, 2008 [1623]), 128–9, 194.

64 Freud, 'New Introductory', 57; Freud, 'Neurosis and Psychosis', 150.

65 For some studies of the causal links between exhortations to hygienic measures during the pandemic and exacerbation of obsessive-compulsive disorders, see Lena Jelinek, Steffen Moritz, Franziska Miegel and Ulrich Voderholzer, 'Obsessive-Compulsive Disorder during COVID-19: Turning a Problem into an Opportunity?', *Journal of Anxiety Disorders* (2021) 77: 1–10; Mona F. Sulaimani and Nizar H. Bagadood, 'Implication of Coronavirus Pandemic on Obsessive-Compulsive-Disorder Symptoms', *Review of Environmental Health* (2021) 36: 1–8; Athanasios Hassoulas, Katja Umla-Runge, Abeer Zahid et al., 'Investigating the Association between Obsessive-Compulsive Disorder Symptom Subtypes and Health Anxiety as Impacted by the COVID-19 Pandemic: A Cross-Sectional Study', *Psychological Reports* (2022) 125: 3006–27; on the Shakespearean meme, Emma Smith, '"Out Damn Spot": The Lady Macbeth Hand-Washing Scene that Became a Coronavirus Meme', *Penguin*, 12 March 2020.

66 Shakespeare, *Macbeth*, 126–7.

67 Jamieson Webster, *Conversion Disorder: Listening to the Body in Psychoanalysis* (New York: Columbia University Press, 2019), 69 (emphasis added). See further for example, 65–8, 73; and Freud, 'The Neuro-Psychosis', 49–50; Freud, 'Further Remarks', 171–3; Freud, 'Inhibitions, Symptoms', 91–8.

68 Freud, 'Inhibitions, Symptoms', 119. Emphasis in original.

69 Shakespeare, *Macbeth*, 129, 194–5.

70 Otto Fenichel, 'The Drive to Amass Wealth', *The Psychoanalytic Quarterly* (1938) 7: 86. On Fenichel, see further Jacoby, *The Repression of Psychoanalysis*. Fenichel has fared marginally better than Jacobson: his Marxist writings were omitted from his *Collected Papers*. Jacoby, *The Repression of Psychoanalysis*, 11. He is summarily dealt with over two pages in Pavón-Cuéllar, *Marxism and Psychoanalysis*, 127–8, without mention of the seminal paper just quoted. But (unlike Jacobson) he receives his dues in Johnston, *Infinite Greed*; see further below. For a somewhat underwhelming attempt to apply Fenichel to the ecological crisis, see Joseph Dodds, 'Otto Fenichel and Ecopsychonalysis in the Anthropocene', *Psychoanalytical Perspectives* (2019) 16: 195–207.

71 Sigmund Freud, 'Fetishism', *The Standard Edition of the Complete Psychological Works of Sigmund Freud: Volume XXI* (London: Hogarth, 1961 [1927]), 152–7; Freud, 'An

Outline', 201–4; and cf. for example, Sigmund Freud, 'Infantile Genital Organization', in *The Standard Edition of the Complete Psychological Works of Sigmund Freud: Volume XIX* (London: Vintage, 2001 [1923]), 143–4. 'Disavowal' is the third concept, alongside 'denial' and 'repression', designating very similar processes; as defined by Zupančič, it is very close to Cohen's and Norgaard's 'implicatory denial'.

72 A nuanced psychoanalytical theory of masculinity, partly critical of Freud, is laid out in Gunnar Karlsson, 'Masculinity as Project: Some Psychoanalytic Reflections', *NORMA: International Journal for Masculinity Studies* (2014) 9: 249–68 (with an allusion to geoengineering on 264).

73 Cohen, *States of Denial*, 27–8.

74 Malm and Carton, *Overshoot*, 159–60. Castration anxiety, in this extended sense of the term, is 'a state of mind in which individuals, women as well as men, must battle throughout the course of their lives against the limitations … brought about through the constraints imposed on them by civilisation' – or, in another extension, against the tightening limitations brought about through the constraints imposed on bourgeois civilisation by the structure of the climate system. Anna Migliozzi, 'Castration and Conformity', *Psychoanalytic Inquiry* (2018) 38: 24–5.

75 Freud, 'Fetishism', 154.

76 Cf. ibid., 156; Cohen, *States of Denial*, 27; Eugene E. Trunnell and William E. Holt, 'The Concept of Denial or Disavowal', *Journal of the American Psychoanalytic Association* (1974) 22: 771, 773.

77 Freud, 'An Outline', 203.

78 Freud, 'Fetishism', 154 (emphasis added).

79 Oliver Morton, *The Planet Remade: How Geoengineering Could Change the World* (London: Granta, 2015), 145; see further, for example, 4, 8. 220, 265.

80 Ibid., 27. In cooperation with Melinda, Bill is said to have saved the lives of as many people as Hitler, Stalin and Mao killed put together. Ibid., 353.

81 Ibid., 372, 338.

82 Keith, *A Case*, 173–4.

83 Smith, *Pandora's Toolbox*, 236.

84 Theodor Adorno, *Minima Moralia: Reflections on Damaged Life* (London: Verso, 2005 [1951]), 53.

85 Cf. Holly Jean Buck, Andrea R. Gammon and Christopher J. Preston, 'Gender and Geoengineering', *Hypatia* (2014) 29: 652–4.

86 Cf. the etymology of 'cloud seeding', or *ensemencement des nuages* in French, from *la semence* for sperm.

87 Heidi J. Nast, 'The Machine-Phallus: Psychoanalyzing the Geopolitical Economy of Masculinity and Race', *Psychoanalytic Inquiry* (2015) 35: 766–85. Reflections – without a gender dimension – on libidinal investment in machines are, of course, common in the corpus of critical theory; for just some examples, see Theodor Adorno, *Introduction to Sociology* (Cambridge: Polity, 2000 [1968]), 76; Theodor Adorno, *Critical Models: Interventions and Catchwords* (New York: Columbia University Press, 2005 [1963/1969]), 201; Marcuse, *Five Lectures*, 54–5. For more on libidinal investment specifically in fossil fuels and their technologies, see Malm and the Zetkin Collective, *White Skin*. For a broader critique of technofixes in climate politics – including geoengineering – as powered by patriarchy, see Jennie C. Stephens, 'The Dangers of Technological Optimism: Why Feminist, Antiracist Values Are Essential for Social Justice, Economic Justice, and Climate Justice', *Environmental Values* (2024) 33: 58–70.

88 For some thoughts on adaptation as fetishistic disavowal, see Zupančič, *Disavowal*, 11–16.
89 Alan Bass, *Difference and Disavowal: The Trauma of Eros* (Stanford: Stanford University Press, 2000), 28. Cf. for example, 182.
90 See ibid., for example, 27–30, 49, 67.
91 Zupančič, *Disavowal*, 88.
92 Cf. Freud, 'Fetishism', 153.
93 Cf. Bass, *Difference and Disavowal*, 53, 58, 67–8.
94 Ibid., 65; cf. Freud, 'Fetishism', 153.
95 Cf. Dodds, *Psychoanalysis and Ecology*, 72; Trunnell and Holt, 'The Concept of Denial', 774.
96 Freud, 'An Outline', 203. In accordance with the splitting of the ego, however, the destruction is a half-measure: the subject keeps acknowledging some aspects of the external world, while being hard at work on 'a substitute for reality'. Ibid., 204; quotation from Freud, 'The Loss of Reality', 187 (emphasis in original removed).
97 Nina Lakhani, Damien Gayle and Matthew Taylor, 'How Criminalisation Is Being Used to Silence Climate Activists across the World', *Guardian*, 12 October 2023. Cf. Constance Gordon, 'Criminalizing Care: Environmental Justice Under Political and Police Repression', *Environmental Communication* (2024) 18: 138–45. Brutal repression of climate and other environmental movements has, of course, always been the rule in the global South, as pointed out in, for example, Gordon, 'Criminalizing Care', 138.
98 See, for example, the above two references, and Damien Gayle, 'Five Just Stop Oil Activists Receive Record Sentences for Planning to Block M25', *Guardian*, 18 July 2024; Trevor Stankiewicz and Linda Lakhdhir, 'On Thin Ice: Disproportionate Responses to Climate Change Protesters in Democratic Countries', Climate Change International, September 2024.
99 Lakhani et al., 'How Criminalisation'.
100 Tadzio Müller, 'Der unbewegte Mann: Klimakampf als Beziehungskonflikt', *Friedliche Sabotage*, 2 May 2024 (emphasis added). See further, for example, Tadzio Müller, 'Dr. JustCollapse: How I Learned to Stop Being Depressed about the Climate and to Love the Future Again', *Friedliche Sabotage*, 7 December 2023; on repression as repression, cf. also DeLay, *Futures of Denial*, 273–7. Palestine activists were, of course, treated in much the same manner, and nowhere more so than in Germany, homeland of political psychopathologies.
101 Some illuminating links between these two types of repression are made in Duncan McLaren and Olaf Corry, '"Our Way of Life Is Not Up for Negotiation!": Climate Interventions in the Shadow of "Societal Security"', *Global Studies Quarterly* (2023) 3: 5–10.
102 Or, in non-Marxist terms, 'We should learn to see, therefore, technology as an event of life that speaks to (and from) the deepest levels of human consciousness.' Frankel and Krebs, *Human Virtuality*, 17.
103 Herbert Marcuse, *Eros and Civilization: A Philosophical Inquiry into Freud* (Boston: Beacon, 1974 [1955]), 52, 86. Cf. Andrew Feenberg, *The Ruthless Critique of Everything Existing: Nature and Revolution in Marcuse's Philosophy of Praxis* (London: Verso, 2023), 125–6. For a reformulation of Marcuse's thesis, which argues for a sublimated death drive as the psychic fuel of technological development – i.e. not all of it is destructive; a lot of it is constructive and salutary – see Benjamin Fong, 'Death Drive Sublimation: A Psychoanalytical Perspective on Technological Development', *Psychoanalysis, Culture and Society* (2013) 18: 352–67.

104 We owe this point to Nicholas LePage.
105 For example, Sam Halpern, ‘IDF Offers Incubators for Gaza Newborns, Aid to Al-Shifa Hospital’, *Jerusalem Post*, 14 November 2023.
106 Performative denial, in other words, would be the psychology of greenwashing.
107 Quoted in Brian Bergman, ‘Climate Contrarian’, *Canadian Geographic* (2006) 126: 76. Keith was against Canada signing the Kyoto agreement, whose targets he thought were ‘very foolish’. Ibid., 82.
108 Keith in Goodell, *How to Cool*, 39–40.
109 Gells, ‘This Scientist’.
110 ‘The overhype of tipping points’ is ‘bad science & it’s profoundly elitist and anti-democratic.’ Moreover, ‘it is inconsistent to say with high confidence that there are sharp here-be-dragons cliffs while also being confident that reducing radiative forcing by SRM cannot help avoid the cliffs. The inconsistency illustrates how this is a political not a scientific effort.’ David Keith, X (Twitter), 6 December 2023. Obviously, the inconsistency could be read in the other direction: Keith being confident that SRM can help avoid the cliffs, while saying that there are none.
111 S. Fred Singer, Roger Revelle and Chauncey Starr, ‘What to Do about Greenhouse Warming: Look Before You Leap’, *Cosmos: A Journal of Emerging Issues* (1992) 5: 28–33. Singer is one of the main characters in Naomi Oreskes and Erik M. Conway, *Merchants of Doubt: How a Handful of Scientists Obscured the Truth on Issues from Tobacco Smoke to Global Warming* (New York: Bloomsbury, 2010).
112 See Muffett and Feit, ‘Fuel to the Fire’, 43–6.
113 Nordhaus, ‘Economic Approaches’, 44, 40. In all its paupericidal madness, the Nordhausian arguments for welcoming high levels of warming and simply adapting to them are recycled and largely endorsed in Smith, *Pandora’s Toolbox*, 68–78.
114 Or rather: faux Nobel Prize. The economics prize that was awarded to Nordhaus was not one of the prizes originally established in Alfred Nobel’s will but set up by the Swedish national bank afterwards.
115 See further Kristoffer Ekberg, Christina Englund, Ståle Holgersen et al., ‘A Green National Paradox? How the Far Right Turned Sweden from a Pioneer of Climate Mitigation to an Obstructor’, *Political Geography*, forthcoming.
116 Kungl. Vetenskapsakademien, ‘The Prize in Economic Sciences 2018’, 8 October 2018.
117 John Hassler, ‘Klimatförändringar och ekonomisk tillväxt’, Nationalekonomiska Föreningens Förhandlingar, 30 March 2011, 85.
118 Christer Fuglesang and John Hassler, ‘Segel i rymden kan bli plan B mot globala uppvärmningen’, *Dagens Nyheter*, 4 March 2020; Christer Fuglesang and John Hassler, ‘Climate Policy in Need of Plan B’, in Ufuk Akcigit and John van Reenen (eds), *The Economics of Creative Destruction: New Research on Themes from Aghion and Howitt* (Cambridge, MA: Harvard University Press, 2023), 411–434.
119 John Hassler, ‘Sveriges klimatstrategi: 46 förslag för klimatomställningen i ljuset av fit-for-55’, Regeringen, October 2023; cf. John Hassler, Per Kågeson and Magnus Nilsson, ‘Dags att pausa de nationella klimatmålen’, *Dagens Nyheter*, 1 June 2024.
120 For anticipations of the turnabout from right-wing or far-right denial to geoengineering, see for example, Nils Markusson, David Tyfield, Jennie C. Stephens and Mads Dahl Gjefsen 2021, ‘Promises of Climate Engineering after Neoliberalism’, in Sapinski et al., *Has It Come*, 208–9; Ryan Gunderson, Diana Stuart and Brian Petersen, ‘The Political Economy of Geoengineering as Plan B: Technological Rationality, Moral Hazard, and New Technology’, *New Political Economy* (2019) 24: 704; Ryan Gunderson, Diana Stuart and Brian Petersen, ‘Materialized Ideology and Environmental Problems: The Cases of Solar Geoengineering and Agricultural Biotechnology’, *European Journal of*

Social Theory 23 (2020): 399; Ott, ‘On the Political’, 7–10; Hamilton, *Earthmasters*, 91–3; McLaren, ‘Mitigation Deterrence’, 598. One empirical study demonstrated that denialists in the general British population were positively inclined towards geoengineering: Adam Corner and Nick Pidgeon, ‘Geoengineering, Climate Change Scepticism and the “Moral Hazard” Argument: An Experimental Study of UK Public Perceptions’, *Philosophical Transactions of the Royal Society A* (2014) 372: 1–14.

121 Keith in Mike Orcutt, ‘Why This Geoengineering Pioneer’s Worst Nightmare Is a Trump Tweet’, *MIT Technology Review*, 7 November 2017.

122 Hugh Hunt and Shaun Fitzgerald, ‘Geoengineering Is Politically Off-Limits – Could a Trump Presidency Change That?’, *The Conversation*, 17 February 2025. These two men were based at the Centre for Climate Repair at Cambridge University.

123 Richard Haass and Carolyn Kissane, ‘Tackling Climate Change in the Age of Trump’, *Project Syndicate*, 17 February 2025.

124 Or, as Dan Farber charmingly put this point: ‘If you decide you’re going to start smoking a lot more cigarettes, you need to be prepared for greater likelihood you’ll need chemo.’ Dan Farber, ‘The 2024 Election Outcome Could Boost the Case for Geoengineering’, *Legal Planet*, 28 October 2024.

125 In his first comments on the second Trump presidency, Keith seemed far less worried than eight years earlier: see Keith in Mark Turner, ‘What Do the Announcements from the New US Administration Mean for SRM?’, *SRM360*, 22 January 2025. Jesse Reynolds suggested that Trump might be suspended between the influence of chemtrail conspiracist Robert F. Kennedy Jr and tech-lover Elon Musk. Only one of the three scholars voicing their opinions in this piece, Jane Long of the Lawrence Livermore National Laboratory, rang the alarm bells: ‘A government that abandons its commitments to eliminating greenhouse gas emissions certainly cannot be trusted with the research of SRM.’

126 See further Malm and the Zetkin Collective, *White Skin*.

127 Ibid., 194.

128 Dharna Noor, ‘What the World Needs Now Is More Fossil Fuels, Says Trump’s Energy Secretary’, *Guardian*, 10 March 2025.

129 Another way to analyse this move, however, would be to say that it breaks with denial and initiates ‘climate barbarism’, as theorised by Jacob Blumenfeld: literal denial is ‘*no longer necessary*. One can now accept the irrefutable truth of climate change without having to give up one’s love of fossil fuels or hatred of immigrants.’ Jacob Blumenfeld, ‘Climate Barbarism: Adapting to a Wrong World’, *Constellations* (2022) 29: 11 (emphasis in original).

130 Bala et al., ‘One Atmosphere’, 11; Smith in Bourke, ‘To Avert’. See further McLaren and Corry, ‘“Our Way of Life”’, 9–10.

131 For the former and more scenarios, see Malm and the Zetkin Collective, *White Skin*.

132 Henry Shue, *The Pivotal Generation*, 20.

133 Robock, ‘20 Reasons’, 16. Psychological approaches are conspicuous by their absence in research on geoengineering, and the rationalist-optimists have no idea how to treat parameters of this stripe, except by bracketing them out. In his attempt to allay concerns about all of the 20 side effects, Wagner skips over this particular warning from Robock and leaves it ‘as an open question.’ Wagner, *Geoengineering*, 58. No rationalist-optimist could ponder it for long and stay true to his axioms.

134 Sigmund Freud, ‘Remembering, Repeating and Working-Through’, in *The Standard Edition of the Complete Psychological Works of Sigmund Freud, Volume XII* (London: Hogarth, 1958 [1914]), 152.

135 McKinnon, ‘Sleepwalking Into’, 449.

136 Nicola Davis, ‘Milky Way No Longer Visible to One Third of Humanity, Light Pollution Atlas Shows’, *Guardian*, 10 June 2016.
137 Robin McKie, ‘Stars Could Be Invisible within 20 Years as Light Pollution Brightens Night Sky’, *Guardian*, 27 May 2023.
138 But there was some: see Joshua Korber Hoffman, ‘Light Pollution Is Getting Worse, But There Is a Movement to Make Our Skies Dark Again’, CNN, 5 February 2025. Again – cf. note 340 on page 472 – Jean-Luc Mélenchon stands out among politicians in the North for his commitment to ‘the right to darkness’ and to starry nights. Mélenchon, *Now, the People!*, 94–6.
139 Robock, ‘20 Reasons’, 16; for a discussion of the causal connection between Munch and Krakatau, see Zerefos et al., ‘Atmospheric Effects’, 4033. 1.2°C: Smith, *Pandora’s Toolbox*, 219.
140 Adorno, *Negative Dialectics*, 24, 347 (emphasis in original).
141 Theodor Adorno, *Philosophy and Sociology* (Cambridge: Polity, 2022 [1960]), 34; Theodor Adorno, *History and Freedom* (Cambridge: Polity, 2008 [1964–65]), 129. Cf. for example, Adorno, *Introduction to Sociology*, 50; Adorno, *Critical Models*, 193; Adorno, *Negative Dialectics*, 23.
142 Adorno and Horkheimer, *Dialectic of Enlightenment*, xiv. Cf. Adorno, *Philosophical Elements*, 65.
143 Theodor Adorno, *Lectures on Negative Dialectics* (Cambridge: Polity, 2008 [1965–66]), 17; Adorno, *Philosophical Elements*, 43.
144 Kintisch, *Hack the Planet*, 243.
145 Freud, ‘Remembering, Repeating’, 152–3.
146 This scenario is discussed in Olaf Corry, ‘The International Politics of Geoengineering: The Feasibility of Plan B for Tackling Climate Change’, *Security and Dialogue* (2017) 48: 306–8; and cf. for example, McLaren, ‘“It’s Not the Climate”’, 265.
147 Halstead, ‘Stratospheric Aerosol’, 70. Or, in the words of the key thinkers themselves: ‘Any unusual weather extremes may be blamed on the SRM deployment’. Keith and MacMartin, ‘A Temporary, Moderate’, 205.
148 Cf. Axel Michaelowa, ‘Solar Radiation Modification – A “Silver Bullet” Climate Policy for Populist and Authoritarian Regimes?’, *Global Policy* (2021) 12: 124.
149 Fleming, *Fixing*, 89, 148–9, 151–3.
150 Ibid., 160.
151 On the looming politicisation of the former, see Victor Alonso-Rocafort, ‘Why Is the Sky Blue? A New Question for Political Science’, *Sustainability Science* (2024) 19: 1161–2.
152 For a good survey, see Rose Cairns, ‘Climates of Suspicion: “Chemtrail” Conspiracy Narratives and the International Politics of Geoengineering’, *The Geographical Journal* (2016) 182: 70–84.
153 Ibid., 74; Alexander Jack and Reena Panchal, ‘Soaring Seas, Forest Fires and Deadly Drought: Climate Change Conspiracies and Mental Health’, *BJPsych Bulletin* (2021) 45: 211.
154 Dustin Tingley and Gernot Wagner, ‘Solar Geoengineering and the Chemtrails Conspiracy on Social Media’, *Palgrave Communications* (2017) 3: 1–7; quotation from 3.
155 Ramit Debnath, David M. Reiner, Benjamin K. Sovacool et al., ‘Conspiracy Spillovers and Geoengineering’, *iScience* (2023) 26: 1–24.
156 Ibid., 9, 13.
157 Thereby conforming to the tendencies described in Richard Seymour, *Disaster Nationalism: The Downfall of Liberal Civilization* (London: Verso, 2024).

158 Christopher Flavelle, ‘Conspiracy Theorists and Vaccine Skeptics Have a New Target: Geoengineering’, *New York Times*, 26 September 2024.

159 Maryanne Christensen in Amy Joi O’Donoghue, ‘Utah Senators Tackle Solar Geoengineering. What Is It?’, KSL News, 3 March 2025. Her membership of said Church: ‘Maryann Christensen’, *Ballotpedia*, 2020. The bill was introduced by Ronald Winterton; on his membership, see Shaun D. Stale, ‘Gospel Taught Loud and Clear in Branch for Deaf’, *Church News*, 9 July 2005.

160 Danielle Goodrich (a fight led by Goodrich and Macbeth, not to forget Christensen) of an outfit called East Tennessee Freedom in Flavelle, ‘Conspiracy Theorists’.

161 Hostility to and advocacy of geoengineering from the far right occupy positions somewhat analogous to green nationalism and anti-climate politics. In both pairs, the second item has considerably greater capacity to align the far right with dominant classes, as well as its own political traditions, although the first item retains potential. Cf. Malm and the Zetkin Collective, *White Skin*. It might be pointed out, however, that the anti-geoengineering activists were better organised in the Republican Party than the opposite camp, as of the mid-2020s.

162 Tingley and Wagner, ‘Solar Geoengineering’, 5. Cf. Wagner, *Geoengineering*, 66–9; Smith, *Pandora’s Toolbox*, 308.

163 Smith, *Pandora’s Toolbox*, 226; cf. 308.

164 Theodor Adorno, *The Stars Down to Earth, and Other Essays on the Irrational in Culture* (London: Routledge, 2002), 155–6, 165–6. Cf. T. W. Adorno, Else Frenkel–Brunswik, Daniel J. Levinson and R. Nevitt Sanford, *The Authoritarian Personality* (London: Verso, 2019 [1950]), 658, 663–5, 671; Adorno, *Negative Dialectics*, 89; Adorno, *Philosophical Elements*, 68; Cairns, ‘Climate of Suspicion’, 76–7.

165 For example, Freud, ‘Introductory Lectures’, 286; Freud, ‘Inhibitions, Symptoms’, 99–100.

166 Freud, ‘Remembering, Repeating’, 152.

167 Smith, *Pandora’s Toolbox*, 236. This choice of quotation is, admittedly, somewhat unfair to Smith. He is undoubtedly the most charming of the rationalist-optimists: the only one a Marxist could possibly read with some enjoyment, he alone has stylistic ambition and – barely heard of among bourgeois intellectuals – a degree of soul-searching and humility. His opposite in both regards is Jesse Reynolds, whose dullness of prose is matched by an absolute rigidity of thinking.

168 Herbert Marcuse, *One-Dimensional Man: Studies in the Ideology of Advanced Industrial Society* (London: Routledge, 2002 [1964]), 159; see further Gunderson et al., ‘The Political Economy’.

169 Adorno, *Philosophy and Sociology*, 77. Cf. for example, 31, 137; Adorno, *Introduction to Sociology*, 133.

170 Adorno, *Philosophical Elements*, 112. ‘This relationship with technology leads to a very peculiar mixture of improvisational ability and obedience, of independent “initiative” (raiding-party mentality) and abstention from independent thinking’ – a diagnosis that could not possibly fit the men of geoengineering (and removal) better. Adorno, ‘The Problem’, 466.

171 Adorno, *Philosophy and Sociology*, 78.

172 Keith, ‘Geoengineering the Climate’, 279. On the forward march of the domination of nature through technologies, including for managing crises, see, for example, Adorno and Horkheimer, *Dialectic of Enlightenment*, 121; Adorno, *Lectures on Negative*, 105; Marcuse, *One-Dimensional Man*, 162; Feenberg, *The Ruthless Critique*, 141–2, 152, 162–4.

173 Keith, ‘Geoengineering the Climate’, 278.

174 Ibid., 279.
175 Frankel and Krebs, *Human Virtuality*, 68.
176 Ibid., 149.
177 To just give one more example from the recent literature on digital tech: Christine Rosen, *The Extinction of Experience: Reclaiming Our Humanity in a Digital World* (London: Penguin, 2024), 2, 117–8, 215.
178 This is the central argument in ibid. – strangely, a study written by a senior fellow at the American Enterprise Institute who hammers home her points with the help of Adorno and Benjamin.
179 Frankel and Krebs, *Human Virtuality*, 268.
180 Ibid., 270.
181 See ibid., for example, 34, 64, 80–3.
182 Ibid., 265; and cf. Rosen, *The Extinction of Experience*, 265.
183 For the workings of that machine, see the most popular – and entirely convincing – study at the moment of this writing: Jonathan Haidt, *The Anxious Generation: How the Great Rewiring of Childhood Is Causing an Epidemic of Mental Illness* (New York: Penguin, 2024).
184 Marx, *Capital. Volume I*, 342, 375, 348.
185 Johnston, *Infinite Greed*, for example, 67-8, 91, 100, 107. Johnston's work is only marred by the popular illusion that Lacan offers anything that can compare with the infinite wisdom of Adorno. Although he engages here and there with the Frankfurt School, Johnston underappreciates it: the school is, for example, said to only 'intermittently register the power of the economy to colonise and remake everything under the sun in its own image.' Ibid., 275. But the registering of this power is rather the essence of the Frankfurt project and developed in, if not all, then an abundance of its texts.
186 Ibid., 107, 123; and see the preparatory Adrian Johnston, 'From Closed Need to Infinite Greed: Marx's Drive Theory', *Continental Thought and Theory* (2017) 1: 270–346. Cf. Sami Khatib, 'The Drive of Capital: Of Monsters, Vampires and Zombies', *Coils of the Serpent* (2021) 8: 101–13; Lucas Pohl and Samo Tomšič, 'The Catastrophic Drive', in Earl T. Harper and Doug Specht (eds), *Imagining Apocalyptic Politics in the Anthropocene* (Abingdon: Routledge, 2022), 142–57. In Freudian contexts, *Trieb*, of course, is often mistranslated as 'instinct'.
187 Marx, *Capital. Volume I*, 375, 353.
188 Ibid., 376.
189 Ibid., 381.
190 Ibid., 376; also 348.
191 Marx, *Grundrisse*, 270. Cf. Johnston, *Infinite Greed*, 123.
192 Johnston, *Infinite Greed*, xviii.
193 Ibid., for example, xix–xx, 105–9, 123.
194 Marx, *Grundrisse*, 270.
195 Adorno, *Negative Dialectics*, 26.
196 Marx, *Capital. Volume I*, 381.
197 Or, alternatively, an id and an ego but no superego: see Andreas Malm, 'The Future Is the Termination Shock: On the Antinomies and Psychopathologies of Geoengineering. Part Two', *Historical Materialism* (2023) 31: 37–8.
198 This is a major theme in Johnston, *Infinite Greed*.
199 Marx, *Capital. Volume I*, 342; and see further for example, Karl Marx, *Capital: A Critique of Political Economy. Volume II* (London: Penguin, 1992 [1885]), 159, 199;

Charles Andrew Prusik, *Adorno and Neoliberalism: The Critique of Exchange Society* (London: Bloomsbury, 2022), 20–22, 36–8; and further Johnston, *Infinite Greed*.

200 Johnston, *Infinite Greed*, 124.

201 Ibid., 219.

202 Fenichel, 'The Drive to Amass'. Johnston aligns with Fenichel in *Infinite Greed*, for example, 67, 88, 94.

203 Fenichel, 'The Drive to Amass', 94.

204 Ibid., 83. Emphasis in original.

205 The theoretical basis for this historicity of the drive to accumulate – and every other drive – is the long helplessness of children, one of the most central insights of psychoanalysis: see Johnston, *Infinite Greed*, for example, 39–41, 94, 107. For another compelling case for the historicity of drives, see Benjamin Fong, *Death and Mastery: Psychoanalytic Drive Theory and the Subject of Late Capitalism* (New York: Columbia University Press, 2016), 10–18. On this as a key contribution of Fenichel and the second generation, see Jacoby, *The Repression of Psychoanalysis*, for example, 74–5, 102–3, 113, 120–1.

206 Pavón-Cuéllar, *Marxism and Psychoanalysis*, 18.

207 Freud, 'An Outline', 201.

208 Cf. Marx, *Capital. Volume III*, 914; Adorno, *History and Freedom*, 72; Johnston, *Infinite Greed*, 125; Prusik, *Adorno and Neoliberalism*, 36–7.

209 Marx, *Capital. Volume I*, for example, 390, 395.

210 Ibid., 381.

211 Ibid., 390.

212 Ibid. There is a gap in the analogy, of course, in that fossil fuels cannot be limited to certain hours of the day – they must be abolished wholesale – but even a reform analogous to a Ten Hours Act, such as a moratorium on new fossil fuel installations, appears impossibly irreconcilable with the *Trieb*. The analogy is strengthened, on the other hand, by the circumstance that fossil energy is only slightly less essential to modern capital accumulation than labour. Indeed, fossil fuels are the energetic substance of the measureless drive. This is why the climate crisis is a moment of truth, or litmus test, for the existence of a reality principle in capital; and so far, all empirical indications point to negative results.

213 Marx seems to miss the difference when he writes that 'the limiting of factory labour was dictated by the same necessity as forced the manuring of English fields with guano'. Ibid., 348. However necessary it might have been, the former limit was solely the deed of the class. On the other hand, the switch to guano was not induced by any uprising: the exhausted soils of England did not revolt, nor was there a farmers' or environmentalist movement commensurate with the ten-hour movement. And, crucially, the switch did not constitute a real limit to the exploitation of the soil, on a par with the Ten Hours Act, but rather a displacement and intensification of it (later taken to new heights with the production of synthetic fertilisers); see the classic analysis of John Bellamy Foster, *Marx's Ecology: Materialism and Nature* (New York: Monthly Review Press, 2000); John Bellamy Foster, Brett Clark and Richard York, *The Ecological Rift: Capitalism's War on the Earth* (New York: Monthly Review Press, 2010). Unaided by resistance, necessity – understood as the imperatives arising from capital breaking boundaries – could only dictate the latter types of exacerbation.

214 Put differently: had the class been what it was in, say, 1918 or 1969, the landscape of political subjectivity in the age of the climate crisis might have looked very different. But such a counterfactual scenario is difficult to even envision.

215 For example, Adorno, ‘Reflections on Class’; Theodor Adorno, ‘Late Capitalism or Industrial Society? The Fundamental Question of the Present Structure of Society’, in *Can One*, 111–25; Adorno, *History and Freedom*, 9.

216 Adorno, *Negative Dialectics*, 320. Emphasis added. Cf. for example, 334–5, 362.

217 Presented in Dodds, *Psychoanalysis and Ecology*, 61; John Keene, ‘Unconscious Obstacles to Caring for the Planet: Facing Up to Human Nature’, in Weintrobe, *Engaging with Climate*, 146. One effective critique of transhistorical psychoanalysis and manifesto for historical concretion is Peter Gay, *Freud for Historians* (Oxford: Oxford University Press, 1985), for example, 27–8, 82, 88–91, 166. A model of such concretion is Weintrobe, *Psychological Roots*.

218 Fenichel, ‘The Drive’, 90–1, 93 (first emphasis in original, second added).

219 Ibid., 71.

220 Or, we might say that denial is charting a course for its long-term endurance, *even as* the proponents of the venture justify it with reference to the severity of the crisis.

221 Kaplan, *Climate Trauma*, 143; Adorno, *Negative Dialectics*, 93.

222 Smith correctly points out that the old distinction between geoengineering as intentional climate change and greenhouse-gas-driven climate change as unintentional has long been obsolete. After the maturation of climate science – he dates the break to the turn of the millennium – large-scale fossil fuel combustion was conducted with knowledge of the results. Smith, *Pandora’s Toolbox*, 290. Cf. already Andy Ridgwell, Chris Freeman and Richard Lampitt, ‘Geoengineering: Taking Control of Our Planet’s Climate?’, *Philosophical Transactions of the Royal Society A* (2012) 370: 4164. The collapse of this distinction, however, merely implies that *both* forms of conscious intervention in the climate system are also fuelled by unconscious processes.

223 Adorno, *Lectures on Negative*, 71.

224 Psychology – psychoanalysis included – has so far stood outside, or been shut out from, research on geoengineering. Typically, Mike Hulme has called for interventions on the subject from ‘anthropologists, artists, historians, philosophers, poets’, all needed ‘to bring us to our senses’ – no mention of psychologists or psychoanalytical theorists. Hulme, *Can Science*, 111. To the best of our knowledge, there is one paper explicitly viewing the phenomenon through a psychological lens, published in 2013, which makes an argument based on substitution. Imagine that geoengineering works perfectly fine: then emissions cuts will be supererogatory. This, contends the author, would spell psychic loss for anticapitalists and other extreme alarmists who have built an identity around the doctrine that only system change can save the planet. They would be shattered, virtually castrated, by the spectacle of a tech that easily fits the bill. Gareth Davies, ‘The Psychological Costs of Geoengineering: Why It May be Hard to Accept Even If It Works’, in Wil C. G. Burns and Andrew L. Strauss (eds), *Climate Change Geoengineering: Philosophical Perspectives, Legal Issues, and Governance Frameworks* (Cambridge: Cambridge University Press, 2013), 59–80. Whatever else could be said about such a speculation, it belongs to the era when substitution was still a credible idea; since 2013, the consensus has, as we have seen, moved towards combination, the controversy restricted to whether this scenario is likely or not. It follows that geoengineering would not be a psychological blow to the left, other than as a defeat uncommonly epochal even as left defeats go. Radical or even revolutionary emissions cuts would be just as urgently needed after as before the launch; the risk is merely that geoengineering – by dint of its psychological implications – make them even harder to achieve. The paucity of psychology stands in sharp contrast to ethics. Hard-working moral philosophers have made it impossible for hard-nosed rationalist-optimists to ignore their objections; no one can claim to write comprehensively on the

topic today without displaying an ethical literacy. But ethics is, by nature, a normative business. While it can inform the discussion about what is good and evil in geoengineering, it has no explanatory power as regards its development in the real world.

225 Marcuse, *One-Dimensional Man*, 194.

18. Empire of the Stratosphere

1 For one ultra-stylised modelling exercise depicting this harmonious outcome, see Piergiuseppe Pezzoli, Johannes Emmerling and Massimo Tavoni, 'SRM on the Table: The Role of Geoengineering for the Stability and Effectiveness of Climate Coalitions', *Climatic Change* (2023) 176: 1–21.

2 Holly Jean Buck, 'Will Solar Geoengineering Bring Nations Together? Or Drive them Apart?', *New York Magazine*, 25 January 2022.

3 Holly Jean Buck, 'Environmental Peacebuilding and Solar Geoengineering', *Frontiers in Climate* (2022) 4: 3.

4 Ibid., 4–5.

5 Kevin Surprise, 'Geopolitical Ecology of Solar Geoengineering: From a "Logic of Multilateralism" to Logics of Militarization', *Journal of Political Ecology* (2020) 27: 228. Cf. Evan Calder Williams, *Combined and Uneven Apocalypse: Luciferian Marxism* (Ropley: Zero Books, 2010).

6 The inevitable divergence is recognised by, for example, Anthony Harding and Juan B. Moreno-Cruz, 'Solar Geoengineering Economics: From Incredible to Inevitable and Half-Way Back', *Earth's Future* (2016) 4: 573; MacMartin et al., 'Technical Characteristics', 1334; Visioni et al., 'Seasonally Modulated', 8; Smith and Henly, 'Updated and Outdated', 10–11. The latter paper also – in a not untypical incoherence – contains the argument that geoengineering will 'make all regions better off' compared to unhampered global heating and therefore put a damper on conflicts. Ibid., 5. The argument presumes that if actor B suffers adverse consequences from the geoengineering amply and fully benefiting actor A, it will refrain from any hostile move because it remembers the even worse consequences of pre-injection global heating or compares the present with a counterfactual world without geoengineering – yet another rationalist assumption disconnected from how conflicts develop in the real world.

7 Bergman, 'Climate Contrarian', 76.

8 As suggested by William Morrissey, 'Avoiding Atmospheric Anarchy: Geoengineering as a Source of Interstate Tension', *Environment and Security* (2024), online first, 18.

9 Reynolds, *Solar Geoengineering*, 178–195; cf. for example, Halstead, 'Stratospheric Aerosol', 70.

10 Reynolds, *Solar Geoengineering*, 191. This scholar pushes rationalism-optimism to its most whimsical extreme. Consider the following dream sentence: 'A hypothetical global administrator could – at least in principle – gather, assess, and share information regarding efficient precautions; identify the injurers, the victims, and the harm; determine the extent to which the harm was caused by solar geoengineering; punish injurers that failed to take these precautions; consider external benefits to third parties; collect funds for compensation, perhaps from those who benefitted and have ability to pay; and compensate victims that had taken appropriate caution.' Ibid., 193. Perhaps it could also bring dead victims back to life. (But at the same time, Reynolds thinks the idea of compensating victims might, after all, do more harm than good: it would cause

administrative expenses, fuel a culture of victims demanding redress and compromise state sovereignty. Ibid., 194.)

11 And in a geoengineered world, such negotiations would inevitably prove *more* difficult because of the greater problems of attribution. These points are made in McLaren and Corry, 'Clash of Geofutures', 30.

12 Wagner, *Geoengineering*, 98. Similar extreme idealism is on display in Simon Nicholson, Sikina Jinnah and Alexander Gillespie, 'Solar Radiation Management: A Proposal for Immediate Polycentric Governance', *Climate Policy* (2018) 3: 322–34.

13 'Pauperism and Free Trade: The Approaching Commercial Crisis', *Dispatches for the New York* Tribune: *Selected Journalism of Karl Marx* (London: Penguin 2007 [1952]), 163. Cf. Hulme, *Can Science*, 51–3; Tang and Kemp, 'A Fate Worse', 13.

14 Anna Lou Abatayo, Valentina Bosetti, Marco Casari et al., 'Solar Geoengineering May Lead to Excessive Cooling and High Strategic Uncertainty', *PNAS* (2020) 117: 13393–8. Cf. for example, Juan B. Moreno-Cruz, 'Mitigation and the Geoengineering Threat', *Resource and Energy Economics* (2015) 41: 260–1; Johannes Emmerling and Massimo Tavoni, 'Exploration of the Interactions between Mitigation and Solar Radiation Management in Cooperative and Non-Cooperative International Governance Settings', *Global Environmental Change* (2018) 53: 244–51.

15 Bourgeois political science has made far too much of free riding as the explanation for the failure of climate mitigation. For an empirical refutation (which stays within the confines of such science) see Michaël Aklin and Matto Mildenberger, 'Prisoners of the Wrong Dilemma: Why Distributive Conflict, Not Collective Action, Characterizes the Politics of Climate Change', *Global Environmental Politics* (2020) 20: 4–27; and further the more compelling Jeff D. Colgan, Jessica F. Green and Thomas N. Hale, 'Asset Revaluation and the Existential Politics of Climate Change', *International Organization* (2021) 75: 586–610. The alternative, laid out by these two papers, is to explain the failure in terms of distributive conflicts: a clash of interests, in which those opposing mitigation have been victorious. The low explanatory power of mainstream game theory as regards non-mitigation does not, however, subtract from the free-driving structure of geoengineering.

16 See, for example, Martin L. Weitzman, 'A Voting Architecture for the Governance of Free-Driver Externalities, with Application to Geoengineering', *Scandinavian Journal of Economics* (2015) 117: 1049–68; Todd L. Cherry, Stephan Kroll, David M. McEvoy and David Campoverde, 'Solar Geoengineering, Free-Driving and Conflict: An Experimental Investigation', *Environmental and Resource Economics* (2024) 87: 1045–60. For rationalist-optimist comments on the free-driver problem, see, for example, Harding and Moreno-Cruz, 'Solar Geoengineering', 569, 573; Wagner, *Geoengineering*, 10, 16.

17 Benjamin K. Sovacool, Chad Baum and Sean Low, 'The Next Climate War? Statecraft, Security, and Weaponization in the Geopolitics of a Low-Carbon Future', *Energy Strategy Reviews* (2023) 45: 9.

18 See further the excellent Morrissey, 'Avoiding Atmospheric'. Unhappy states could also try to engage in their own local or regional weather modification efforts, which in their turn could have negative consequences on others downstream, and so on: ibid., 16.

19 For example, ibid., 14–15; Sovacool et al., 'The Next', 5, 12–13.

20 A. Parker, J. B. Horton and D. W. Keith, 'Stopping Solar Geoengineering Through Technical Means: A Preliminary Assessment of Counter-Geoengineering', *Earth's Future* (2018) 6: 1058–65; and for an especially formulaic attempt to turn the threat of counter-geoengineering into a stimulus for co-operation, see also Daniel Heyen, Joshua Horton and Juan Moreno-Cruz, 'Strategic Implications of Counter-Geoengineering:

Clash or Cooperation?', *Journal of Environmental Economics and Management* (2019) 95: 153–77. Another version of this rationalist argument against the possibility of counter-geoengineering is that no state would risk the backlash from deliberately subverting injections; but there might just as well be broad support for doing so, if they have considerable side effects, as pointed out by Morrissey, 'Avoiding Atmospheric', 11.

21 Parker et al., 'Stopping Solar', 1062.

22 Cf. Bronislaw Szerszynski, Matthew Kearnes, Phil Macnaghten et al., 'Why Solar Radiation Management and Democracy Won't Mix', *Environment and Planning A* (2013) 45: 2812; Geoff Mann and Joel Wainwright, *Climate Leviathan: A Political Theory of Our Planetary Future* (London: Verso, 2018), 222.

23 Kevin Surprise, 'Stratospheric Imperialism: Liberalism, (Eco)modernization, and Ideologies of Solar Geoengineering Research', *Environment and Planning E: Nature and Space* (2020) 3: 154.

24 Keith, *A Case*, 153.

25 MacMartin et al., 'Technical Characteristics', 1335–6. On this preference for technocracy among geoengineering modellers, cf. McLaren and Corry, 'Clash of Geofutures', 25.

26 MacMartin et al., 'Technical Characteristics', 1335. Arguments for the incompatibility are outlined in Szerszynski et al., 'Why Solar'; cf. Holly Lawford-Smith, 'Democratic Authority to Geoengineer', *Critical Review of International Social and Political Philosophy* (2020) 23: 600–17.

27 Joshua B. Horton, Jesse L. Reynolds, Holly Jean Buck et al., 'Solar Geoengineering and Democracy', *Global Environmental Politics* (2018) 18: 5–24.

28 Ibid., 8.

29 The same would apply to space-based geoengineering: Baum et al., 'Between the Sun', 15.

30 Andrew Lockley, Ishita Mundra and Patrick Taylor Smith, 'Legitimacy and Justifiability of Non-State Geoengineering', *Futures* (2023) 152: 9–10. The billionaire scenario is sometimes known as the 'greenfinger': see, for example, Sovacool et al., 'The Next', 7. There is also a subset of scenarios in which 'decentralised' or 'DIY' geoengineering is launched by non-state actors; this would take the form of thousands of small balloons released into the stratosphere, à la Make Sunsets or SATAN. See for example, Jesse L. Reynolds and Gernot Wagner, 'Highly Decentralized Solar Geoengineering', *Environmental Politics* (2020) 29: 917–33. This seems even less likely than Lockley's scenarios, which at least depict some kind of coherent entity undertaking the operation.

31 Kristine C. Harper, *Make It Rain: State Control of the Atmosphere in Twentieth-Century America* (University of Chicago Press, 2017), 162; John C. Moore, Ying Chen, Xuefeng Cui et al., 'Will China Be the First to Initiate Climate Engineering?', *Earth's Future* (2016) 4: 588–95; Bettina Bluemling, Rakhyun E. Kim and Frank Biermann, 'Seeding the Clouds to Reach the Sky: Will China's Weather Modification Practices Support the Legitimization of Climate Engineering?', *Ambio* (2020) 49: 365–73; Michaelowa, 'Solar Radiation', 121, 124; Hamilton, *Earthmasters*, 141–5.

32 See, for example, Danielle N. Young, 'Who Can Govern from a House on Fire? International Order, State Responsibility, and the Problem of Solar Radiation Modification', *Ethics and International Affairs* (2024) 38: 245–6; Morrisey, 'Avoiding Atmospheric', 13.

33 For the first decades of this obstruction, see David Ciplet, J. Timmons Roberts and Mizan R. Khan, *Power in a Warming World: The New Global Politics of Climate Change and the Remaking of Environmental Inequality* (Cambridge, MA: MIT Press, 2015).

34 Neta C. Crawford, *The Pentagon, Climate Change, and War: Charting the Rise and Fall of US Military Emissions* (Cambridge, MA: MIT Press, 2022), 129, 257.
35 Cf. Morrissey, 'Avoiding Atmospheric', 14.
36 Cf. Smith et al., 'On Thin Ice', 2–3.
37 We here draw on Kevin Surprise, 'Geopolitical Ecology of Solar Geoengineering: From a "Logic of Multilateralism" to Logics of Militarization', *Journal of Political Ecology* (2020) 27: 222–3, 226–7. Cf. for example, Paul Nightingale and Rose Cairns, 'The Security Implications of Geoengineering: Blame, Imposed Agreement and the Security of Critical Infrastructure', Climate Geoengineering Governance Working Papers Series, 18, University College London, University of Sussex and University of Oxford, 2014, 5, 10; Young, 'Who Can', 246.
38 Christopher Flavelle, 'The US Is Building an Early Warning System to Detect Geoengineering', *New York Times*, 28 November 2024.
39 See Crawford, *The Pentagon, Climate*, for example, 103–26, 181, 197–8, 203–24; and cf., for geoengineering, for example, Robert J. Lempert and Don Prosnitz, 'Governing Geoengineering Research: A Political and Technical Vulnerability Analysis of Potential Near-Term Options', RAND Corporation, 18 April 2011.
40 Loewenstein, *The Palestine*, 49–51.
41 For the mass of disturbing details, see ibid. in its entirety.
42 For some of the history of this impulsion and fuel delivery, see Malm, *The Destruction*.
43 Harry Davies and Yuval Abraham, 'Revealed: Microsoft Deepened Ties with Israeli Military to Provide Tech Support during Gaza War', *Guardian*, 23 January 2025.
44 Sophia Goodfriend, 'With Gaza War and Trump's Return, Silicon Valley Embraces a Military Renaissance', *+972 Magazine*, 31 December 2024.
45 Loewenstein, *The Palestine*, 9.
46 Ibid., 207.
47 Cf. Morrissey, 'Avoiding Atmospheric', 17.
48 The best recent account of this history is Adam Hanieh, *Crude Capitalism: Oil, Corporate Power, and the Making of the World Market* (London: Verso, 2024). The literature on the entanglement of US power and oil in particular is, of course, enormous; yet as Ed McNally has pointed out, a focused environmental history of this empire remains to be written (personal communication).
49 See Malm and Carton, *Overshoot*.
50 See the excellent Timothy C. Lehmann, 'Honourable Spoils? The Iraq War and the American Hegemonic System's Eternal and Perpetual Interest in Oil', *The Extractive Industries and Society* (2019) 428–42.
51 So far, more interest in – including financial support for – geoengineering research has come from the ecomodernist, high-tech, Silicon Valley fractions of the US capitalist class than from the fossil fuel companies themselves. This is amply demonstrated in Kevin Surprise and J. P. Sapinski, 'Whose Climate Intervention? Solar Geoengineering, Fractions of Capital, and Hegemonic Strategy', *Capital and Class* (2023) 47: 539–64. This study, however, is marred by the belief that there is an ongoing 'decline of fossil capital' and a rise of something called 'climate capital'. Ibid., 4, 11. Low costs of renewable energy are said to tilt the latter fraction against the former and drive it to ascendancy. If such propositions were possible to make before 2022, they are conspicuously erroneous after the events of that year: see Malm and Carton, *Overshoot*. Even if fossil fuel companies did not directly fund the emerging geoengineering enterprise, the point is that *the American state* could launch it to protect capital as a whole, by squaring the contradiction between its modus operandi and the climate system; and the capital it would most effectively protect would be primitive fossil. The

ascendancy of fossil capital remains unbroken; there is no such thing as ‘climate capital’. The planes would take the former under their wings.

52 Crawford, *The Pentagon, Climate*, 7–8.

53 See ibid., 25–99.

54 Ibid., 132–4.

55 Ibid., for example, 129, 147, 152, 257.

56 Ibid., 110–26, 130, 254.

57 Crawford tries to put a positive gloss on this potential in ibid., 243–4. This naivety is among the weaknesses of her study, ably pointed out in Ed McNally, ‘Green Empire?’, *Sidecar*, 2 February 2023. On the difficulties of replacing fossil fuels in aviation, see Malm and Carton, *Overshoot*, 184–5; the problems with biofuels in general are by now obvious.

58 Smith and Wagner, ‘Stratospheric Aerosol’, 3; Smith, *Pandora’s Toolbox*, 240–1.

59 Cf. Sovacool et al., ‘The Next’, 8–9.

60 Reynolds, *Solar Geoengineering*, 207.

61 Nightingale and Cairns, ‘The Security Implications’, 5, 9–10; Surprise, ‘Geopolitical Ecology’, 227; McKinnon, ‘The Panglossian Politics’, 590; Morrissey, ‘Avoiding Atmospheric’, 13–14. The threat of malefactors might come from within as well as from without. Geoengineering would presumably rely on a great deal of advanced software and algorithmic programmes vulnerable to cyberattack, including from disgruntled workers. The system ‘would likely depend on a large workforce and have numerous reasons for controversy’: anti-geoengineering cyber-terrorism of proletarian or other subaltern character would be an inherent risk. Tang and Kemp, ‘A Fate Worse’, 9.

62 Sovacool et al., ‘The Next’, 4.

63 Morrissey, ‘Avoiding Atmospheric’, 13.

64 Then again, this might be ascribing too much rationality to the leaders of this country, who in early 2025 appeared engaged in plenty of self-harm. Clearly, the faculty of rational behaviour could not be assumed even in the most self-interested of situations.

65 Whether the US is actually undergoing comparative decline is, of course, a controversial topic, as is the nature of the rekindled rivalry; we shall leave out a deeper discussion of these factors here.

66 Surprise, ‘Stratospheric Imperialism’; and cf. Surprise, ‘Geopolitical Ecology’; Surprise, ‘Gramsci in the Stratosphere’.

67 Anthony R. Harding, Katharina Ricke, Daniel Heyen et al., ‘Climate Econometric Models Indicate Solar Geoengineering Would Reduce Inter-Country Income Inequality’, *Nature Communications* (2020) 11: 1–9 (quotations from 4).

68 Three northern countries accounted for the vast bulk of all research: the US on top, of course, followed by the UK and Germany. Zachary Dove, Arien Hernandez, Shuchi Talati and Sikina Jinnah, ‘Global Perspectives on Solar Geoengineering: A Novel Framework for Analyzing Research in Pursuit of Effective, Inclusive, and Just Governance’, *Energy Research and Social Science* (2024) 118: 1–18. See further references in note 28 page 578.

69 See for example, Olúfemi O. Táíwò and Shuchi Talati, ‘Who Are the Engineers? Solar Geoengineering Research and Justice’, *Global Environmental Politics* (2022) 22: 12–18; and cf. A. Atiq Rahman, Paulo Artaxo, Asfawossen Asrat et al., ‘Developing Countries Must Lead on Solar Geoengineering Research’, *Nature* (2018) 556: 22–4.

70 For one critique of such pretexts, see Surprise, ‘Stratospheric Imperialism’, 152–5.

71 ‘Putting Developing Countries at the Centre of the SRM Conversation’, The DEGREES Initiative, 2022.

72 ‘Our Funders’, The DEGREES Initiative, 2022. Dustin Moskovitz was behind Open Philanthropy. Open Philanthropy, ‘Behind Us’, 2022. Richard Branson was behind The Carbon War Room. RMI, ‘Carbon War Room’, 2024. Facebook executive: Matt Cohler of the Cohler Charitable Fund. Heir of Hyatt: Rachel Pritzker of the Pritzker Innovation Fund. Corbin Hiar, ‘Flubbed Climate Test Won’t Deter Rich Donors from Altering the Sky’, *E and E News*, 18 June 2024. (Pritzker was involved in the marine cloud brightening experiment that was botched in Alameda. Ibid.) The IKEA Foundation gave to the European Climate Foundation. All of these institutions funded the DEGREES Initiative. DEGREES: innovative acronym for ‘DEveloping country Governance REsearch and Evaluation for SRM’.

73 Chukwumerije Okereke, ‘My Continent Is Not Your Giant Climate Laboratory’, *New York Times*, 18 April 2023.

74 Some studies indicate a considerable willingness among Southern audiences to consider geoengineering out of sheer desperation about global warming: for example, Wylie A. Carr and Laurie Yung, ‘Perceptions of Climate Engineering in the South Pacific, Sub-Saharan Africa, and North American Arctic’, *Climatic Change* (2018) 147: 119–32; Chad M. Baum, Livia Fritz, Sean Low and Benjamin K. Sovacool, ‘Public Perceptions and Support of Climate Intervention Technologies Across the Global North and Global South’, *Nature Communications* (2024) 15: 1–15. However, the most extensive study to this date also indicates considerable concerns about geoengineering further entrenching inequities between North and South and having a range of other negative consequences: Sean Low, Livia Fritz, Chad M. Baum and Benjamin K. Sovacool, ‘Public Perceptions on Solar Geoengineering from Focus Groups in 22 Countries’, *Communications Earth and Environment* (2024) 5: 1–19.

75 Cf. for example, Biermann and Möller, ‘Rich Man’s’, 154; Pflugfelder, *Geoengineering*, 7.

76 Frank Biermann and Aarti Gupta, ‘A Paradigm Shift? African Countries Call for the Non-Use of Solar Geoengineering at UN Environment Assembly’, *PLOS Climate* (2024) 3: 1–4; Duncan McLaren and Olaf Corry, ‘Solar Geoengineering Research Faces Geopolitical Deadlock’, *Science*, (2025) 387: 28–30.

77 Quotation in Fleming, *Fixing the Sky*, 209.

78 For this type of contextualisation, see Julia Schubert, ‘Science-State Alliances and Climate Engineering: A “Longue Durée” Picture’, *WIREs Climate Change* (2022) 13: 1–13.

79 Fleming, *Fixing the Sky*, 15–48.

80 Ibid., 49–50.

81 The story is told in full in Philipp Lehmann, *Desert Edens: Colonial Climate Engineering in the Age of Anxiety* (Princeton: Princeton University Press, 2022), 72–114.

82 Fleming, *Fixing the Sky*, for example, 166.

83 Ibid., 61–4.

84 Wagner, *Geoengineering*, 64. This is slightly odd given Wagner’s co-authorship of Smith and Wagner, ‘Stratospheric Aerosol’, based on the consultations with military contractors mentioned above.

85 George C. Kenney quoted in Fleming, ‘The Climate Engineers’, 53.

86 See Fleming, *Fixing the Sky*, 170–1.

87 Jacob Darwin Hamblin, *Arming Mother Nature: The Birth of Catastrophic Environmentalism* (Oxford, New York: Oxford University Press, 2013), 205–9.

88 Schubert, ‘Science-State Alliances’, 5; Fleming, *Fixing the Sky*, 176.

89 Quoted in Harper, *Make It Rain*, 160.

90 Fleming, ‘The Climate Engineers’, 54–5.
91 H.T. Orville and Collier’s Weekly, ‘Weather Made to Order?’, *Collier’s Weekly*, 28 May 1954, 29.
92 Fleming, *Fixing the Sky*, 179–80; Hamblin, *Arming Mother*, 202–3; Harper, *Make It Rain*, 222. There were earlier attempts at cloud seeding as part of counterinsurgency in Vietnam, Korea and possibly Cuba, too, during this period, as well as somewhat less nefarious campaigns in India, Pakistan, the Philippines and Japan, as described in Fleming, *Fixing the Sky*, 181–2 and Harper, *Make It Rain*, 201–2, 204–17.
93 Fleming, ‘The Climate Engineers’, 55.
94 Ibid., 54; Fleming, *Fixing the Sky*, 181.
95 Hamblin, *Arming Mother*, 205.
96 David W. Keith, ‘Toward Constructive Disagreement about Geoengineering’, *Science* (2021) 374: 814.
97 As argued in McLaren and Corry, ‘“Our Way of Life”’, 11.
98 Jeremy Baskin, *Geoengineering, the Anthropocene and the End of Nature* (Cham: Springer, 2019), 30. The scientist in question was Julian Huxley, physicist and later founder of UNESCO. See also Waldemar Kaempffert, ‘Julian Huxley Pictures the More Spectacular Possibilities That Lie in Atomic Power’, *New York Times*, 9 December 1945.
99 H. Wexler, ‘Modifying Weather on a Large Scale’, *Science* (1958) 128: 1061.
100 See further Fleming, *Fixing the Sky*, 201–4.
101 Goodell, *How to Cool*, 78.
102 Ibid., 80–1.
103 Ibid., 80–1.
104 The whole story is narrated in some detail in ibid., 70–87.
105 Hamblin, *Arming Mother*, 138–48; quotation from NATO report on 138.
106 Tamzy J. House, James B. Near Jr., William B. Shields et al., ‘Weather as a Force Multiplier: Owning the Weather in 2025’ (Fort Belvoir, VA: Defense Technical Information Center, 1 August 1996), vi.
107 Peter Schwartz and Doug Randall, ‘An Abrupt Climate Change Scenario and Its Implications for United States National Security’ (Fort Belvoir, VA: Defense Technical Information Center, 1 October 2003), quotation from 1. For more on this by now infamous report, see Mark Townsend and Paul Harris, ‘Now the Pentagon Tells Bush: Climate Change Will Destroy Us’, *Guardian*, 22 February 2004; Fleming, *Fixing the Sky*, 254; Crawford, *The Pentagon, Climate*, 209–11.
108 On the CIA and the Pentagon branches, see for example, Goodell, *How to Cool*, 126, 211–12; Hamilton, *Earthmasters*, 120–31; Catherine M. Schkoda, Shawna G. Cuan and E. D. McGrady, ‘Examining Long-Term Climate-Related Security Risks through the Use of Gaming and Scenario Planning’, *MCU Journal*, 8 November 2016, 114–38; Caitlin Werrell and Francesco Femia, ‘CIA Director on the Geopolitical Risks of Climate Geoengineering’, The Center for Climate and Security, 25 July 2016; *Economist*, ‘America’s Defense Department Is Looking for Rogue Geoengineers’, 2 November 2022. On Harvard, see Surprise, ‘Stratospheric Imperialism’.
109 For some reflections on the death drive in the related context of fossil fuels and the far right, see Malm and the Zetkin Collective, *White Skin*, 502–6.
110 Jacob Blumenfeld, ‘Welcome to the Anderscene’, *The Brooklyn Rail*, July/August 2024. Anders seems poised for an English-language discovery (but as of this writing, his main texts remain unavailable in English). A disastrous, borderline-psychotic attempt to apply his theories to present concerns, including those related to geoengineering, is Babette Babich, *Günther Anders’ Philosophy of Technology: From Phenomenology to Critical*

Theory (London: Bloomsbury, 2023). A professor of philosophy at Fordham University, Babich uses Anders to support all sorts of conspiracy theories, including the chemtrails theory – possibly the first time it has received this intellectual stamp of approval – and a muddled defence of climate denial. Ibid., 57, 101, 116, 209, 217–18, 222, 225. She also rails against 5G and the vaccines and lockdowns of the Covid-19 pandemic. For a characteristically excellent introduction to Anders and his theory of technology, see Enzo Traverso, 'Auschwitz and Hiroshima: Günther Anders', *Historical Materialism* (2024) 32: 100–23.

111 Blumenfeld, 'Welcome to the Anderscene'.

112 University: Rochester Institute of Technology. CV: Andy Haverly, LinkedIn, accessed 1 March 2025. Paper: Andy Haverly, 'Nuclear Explosions for Large Scale Carbon Sequestration', *arXiv*, 14 January 2025, 3. This paper had, in other words, yet to pass peer review. Haverly was a PhD student at the time of posting his paper at *arXiv*; he was 'working with a professor to put together a full-blown paper' and had received 'positive interest from physicists in Germany and the US, as well as marine experts who have been working on unexploded ordnance around the UK coastline'. Joe Banks, 'The Man Who Wants to Save the Planet by Nuking the Earth's Crust', *Vice*, 13 March 2025.

113 Banks, 'The Man'.

114 Quotations from Haverly, 'Nuclear Explosions', 3, 4.

115 Smith, *Pandora's Toolbox*, 276–7.

116 For example, Jay Michaelson, 'Geoengineering and Climate Management: From Marginality to Inevitability', in Burns and Strauss, *Climate Change*, 107–8; Rita Floyd, 'Solar Geoengineering: The View from Just War/Securitization Theories', *Journal of Global Security Studies* (2023) 8: 12; Kintisch, *Hack the Planet*, 69; Wagner, *Geoengineering*, 16, 63, 75, 89; Barrett, 'The Incredible Economics', 45–6, 53; Harding and Moreno-Cruz, 'Solar Geoengineering', 574; Fabre and Wagner, 'Availability of Risky', 3.

117 The early 2030s is suggested as a realistic starting date by Smith and Wagner, 'Stratospheric Aerosol', 124; NASEM, *Reflecting Sunlight*, 124. Smith pushes back this date to mid-century in Smith et al., 'On Thin Ice', 3.

118 Andy Parker and Peter J. Irvine, 'The Risk of Termination Shock from Solar Geoengineering', *Earth's Future* (2018) 6: 460.

119 Ibid., 461. Cf. for example, Halstead, 'Stratospheric Aerosol', 69; Reynolds, 'Is Solar', 4.

120 As argued by McKinnon, 'The Panglossian Politics', 588–9. Another proposal for effective defence is geographical dispersion of the system, equally elegantly debunked as illusory in ibid., 587–8.

121 Wagner, *Geoengineering*, 61.

122 Keith and MacMartin, 'A Temporary, Moderate', 204. Healthcare and farming: Parker and Irvine, 'The Risk of Termination', 465. Satellites and internet: Rabitz, 'Governing the Termination', 518.

123 Reynolds et al., 'Five Solar', 563; Rabitz, 'Governing the Termination', 508–9.

124 Wagner, *Geoengineering*, 61.

125 For example, Parker and Irvine, 'The Risk of Termination', 463–4; Halstead, 'Stratospheric Aerosol', 69; Rabitz, 'Governing the Termination', 505–6; Reynolds, *Solar Geoengineering*, 66.

126 The argument is made in all its naivety in Rabitz, 'Going Rogue?', 105; Rabitz, 'Governing the Termination', 512. On the long exposure to exogenous shocks, see Tang and Kemp, 'A Fate Worse', 10.

127 For example, Reynolds et al., ‘Five Solar’, 563; Parker and Irvine, ‘The Risk of Termination’, 459; Wagner, *Geoengineering*, 60.
128 Reynolds, *Solar Geoengineering*, 40. The rationalist Reynolds thus manages to argue that no termination shock will happen because 1.) any negative side effects will be discovered and the system discontinued early on, and 2.) the system will continue in operation for however long it’s needed, beyond any risk of shock. Reynolds, *Solar Geoengineering*, 40, 66.
129 Duran-Nebreda et al., ‘On the Multiscale’, 742.

Conclusion

1 On the explosion in these years, see Manjana Milkoreit, ‘Social Tipping Points Everywhere? Patterns and Risks of Overuse’, *WIREs Climate Change* (2023) 14: 4–5. For an early piece, see J. David Tàbara, Niki Frantzeskaki, Katharina Hölscher et al., ‘Positive Tipping Points in a Rapidly Warming World’, *Current Opinion in Environmental Sustainability* (2018) 31: 120–9.
2 Simon Sharpe and Timothy M. Lenton, ‘Upward-Scaling Tipping Cascades to Meet Climate Goals: Plausible Grounds for Hope’, *Climate Policy* (2021) 21: 421.
3 Paul D. L. Ritchie, Jesse F. Abrams, David I. Armstrong McKay et al., ‘Tipping Points: Both Problem and Solution’, *One Earth* (2023) 6: 1613. Cf. 1612; Milkoreit, ‘Social Tipping’, 7.
4 The climate movements of 2018–20 were seen as potential heralds of a positive tipping point in Ilona M. Otto, Jonathan F. Donges, Roger Cremades et al., ‘Social Tipping Dynamics for Stabilizing Earth’s Climate by 2050’, *PNAS* (2020) 177: 2354–65; Ritchie et al., ‘Tipping Points’, 1612.
5 As proposed in Otto et al., ‘Social Tipping’, 2357.
6 Ibid., 2360.
7 Cf. Milkoreit, ‘Social Tipping’, 3–4.
8 Another manifestation, then, of property dualism substance monism: see further Malm, *The Progress*. Revolutions in society should here be understood precisely as *combinations* of natural and social components – and none more so, of course, than climate revolutions, if any were ever to transpire.
9 Smith, *Pandora’s Toolbox*, 147.
10 Mara van der Lugt, *Hopeful Pessimism* (Princeton: Princeton University Press, 2025), for example, xvii, 108, 139–40.
11 Ibid., 139.
12 V. I. Lenin, *“Left-Wing” Communism: An Infantile Disorder*, in *Collected Works. Volume 31* (Moscow: Progress Publishers, 1974 [1920]), 99. Cf. Anita Engels and Jochem Marotzke, ‘Assessing the Plausibility of Climate Futures’, *Environmental Research Letters* (2023) 18: 1.
13 Oliver Eagleton, ‘Therborn’s World Casting’, *New Left Review* (2023) 144: 65.
14 Quoted in Mark D. Steinberg, *The Russian Revolution 1905–1921* (Oxford: Oxford University Press, 2017), 86.
15 Quotations in ibid., 39, 23. The references here are to the February revolution. Steinberg shows extensively how unexpected it was.
16 Walter Benjamin, ‘On the Concept of History’, in *Selected Writings. Volume 4, 1938–1940* (Cambridge, MA: Harvard University Press, 2006 [1940]), 397.
17 On Anders following Benjamin, see Traverso, ‘Auschwitz and Hiroshima’, 119–20.

18 Hannah Arendt, ‘What Is Freedom?’, in *Between Past and Future* (New York: Penguin, 2006 [1958]), 169 (emphasis added). One might add: much as every technology has an element of magic to it, every revolution has one of the miraculous.

19 This being a term used by the Axis of Resistance, before its apparent demise after the decimation of Hizbollah. Cf. Kassem Kassir, ‘The Phrases “Unity of Fields [of Battle]”, “Unity of Fronts” or “Axis of Resistance”: Between Slogan and Reality’, *Institute for Palestine Studies*, 2023.

20 This was argued by Max Ajl, ‘Andreas Malm’s *Corona, Climate, Chronic Emergency*’, *Brooklyn Rail*, November 2020. A somewhat similar critique of geoengineering *in toto*, including carbon removal, is given in Mirowski, *Never Let*, 340–2. We are here broadly in line with the position on removal developed in Buck, *After Geoengineering*.

21 For enemy deployment and side effects of renewable energies, see Malm and Carton, *Overshoot*.

22 Andy Reisinger, Jan S. Fuglestvedt, Anna Pirani et al., ‘Overshoot: A Conceptual Review of Exceeding and Returning to Global Warming of 1.5°C’, *Annual Review of Environment and Resources* (2025) 50: 19. Cf. note 7 on page 441.

23 This aligns with arguments developed in Troy Vettese, ‘To Freeze the Thames: Natural Geo-Engineering and Biodiversity’, *New Left Review* (2018) 111: 63–85; Drew Pendergrass and Troy Vettese, *Half-Earth Socialism: A Plan to Save the Future from Extinction, Climate Change and Pandemics* (London: Verso, 2022).

24 Cf. Benjamin K. Sovacool, Chad M. Baum, Sean Low et al., ‘Climate Policy for a Net-Zero Future: Ten Recommendations for Direct Air Capture’, *Environmental Research Letters* (2022) 17: 14.

25 Cf. Jay Fuhrman, Candelaria Bergero, Marldee Weber et al., ‘Diverse Carbon Dioxide Removal Approaches Could Reduce Impacts on the Energy-Water-Land System’, *Nature Climate Change* (2023) 13: 341–50; Chiquier et al., ‘Integrated Assessment’.

26 Cf. Nawaz et al., ‘Agenda for a Progressive’, 21–2; Grubert and Talati, ‘The Distortionary Effects’, 14.

27 Cf. Nawaz et al., ‘Agenda for a Progressive’, 13.

28 Cf. ibid., 3, 21–2.

29 Cf. Myles Allen, Kaya Axelsson, Ben Caldecott et al., ‘The Oxford Principles for Net Zero Aligned Carbon Offsetting’, University of Oxford, September 2020.

30 Possibly with the one exception of concrete and asphalt.

31 Nawaz et al., ‘Agenda for a Progressive’, 23.

32 Cf. ibid., 16, 22–4, 34–7.

33 Ibid., 35; Grubert and Talati, ‘The Distortionary Effects’, 1.

34 Buck, *After Geoengineering*, 136, 203–6.

35 For example, Lackner, ‘Washing Carbon’, 71; Lackner et al., ‘The Urgency of the Development’, 13159; Broecker, ‘Does Air’, 2; Realmonte et al., ‘An Inter-Model Assessment’, 7.

36 For further proposals along these lines, see Duncan McLaren and Olaf Corry, ‘Carbon Dioxide Removal: What Is Sustainable and Just?’, *Environment: Science and Policy for Sustainable Development* (2025) 67: 59–69; Sara Nawaz, Duncan McLaren, Holly Caggiano et al., ‘Carbon Removal for a Just Transition’, *Climate Policy* (2024), online first.

37 Michael Levien, ‘Reactionary Decarbonization: On Carbon Capture and Techno-Utopianism’, *Spectre*, 21 January 2025.

38 Ibid.

39 More concretely: total destruction of fossil capital, total transition to an economy running on the flow. As shown in *Overshoot*, this is technically possible; and scholars of

flow technologies have made the compelling case that their recent advances now put a return to Holocene climate conditions – below 1.5°C, which, as we have seen, comes with unacceptable risks for crossing tipping points – within reach. Benjamin W. Abbott, Chelsea Abrahamian, Nicholas Newbold et al., 'Accelerating the Renewable Energy Revolution to Get Back to the Holocene', *Earth's Future* (2023) 11: 1–14; and cf. Breyer et al., 'Proposing'.

40 Pierre Friedlingstein et al., 'Global Carbon Budget 2023', 5327.

41 Rogelj et al., 'A New Scenario'; Susanne Baur, Alexander Nauels, Uta Klönne and Carl-Friedrich Schleussner, 'The Science of Temperature Overshoots: Impacts, Uncertainties and Implications for Near-Term Emissions Reductions', *Climate Analytics*, October 2021, 15–17.

42 On some counts, this is about four times higher than what can responsibly be squeezed out of nature. Deprez et al., 'Sustainability Limits', 485.

43 William F. Lamb, Thomas Gasser, Rosa M. Roman-Cuesta et al., 'The Carbon Dioxide Removal Gap', *Nature Climate Change* (2024) 14: 644–51.

44 This aligns with the non-militant, governmental action against geoengineering proposed in, for example, Frank Biermann, Jeroen Oomen, Aarti Gupta et al., 'Solar Geoengineering: The Case for an International Non-Use Agreement', *WIREs Climate Change* (2022) 13: 1–8; Aarti Gupta, Frank Biermann, Ellinore van Driel et al., 'Towards a Non-Use Regime on Solar Geoengineering: Lessons from International Law and Governance', *Transnational Environmental Law* (2024), online first.

Acknowledgements

1 The main publications that we have relied on here, in reverse chronological order, are: Kate Dooley, Kristine Lund Christiansen, Jens Friis Lund et al., 'Over-Reliance on Land for Carbon Dioxide Removal in Net-Zero Climate Pledges', *Nature Communications* (2024) 15: 1–10; Jens Friis Lund, Nils Markusson, Wim Carton et al., 'Net Zero and the Unexplored Politics of Residual emissions', *Energy Research and Social Science* (2023) 98: 1–6; Andreas Malm, 'The Future is the Termination Shock: On the Antinomies and Psychopathologies of Geoengineering. Part Two', *Historical Materialism* (2023) 31: 3-61; Wim Carton, Inge-Merete Hougaard, Nils Markusson et al., 'Is Carbon Removal Delaying Emission Reductions?', *WIREs Climate Change* (2023) 14: 1-18; Holly Jean Buck, Wim Carton, Jens Friis Lund et al., 'Why Residual Emissions Matter Right Now', *Nature Climate Change* (2023) 13: 351–358; Andreas Malm, 'The Future Is the Termination Shock: On the Antinomies and Psychopathologies of Geoengineering. Part One', *Historical Materialism* (2022) 30: 3-53; Andreas Malm and Wim Carton, 'Seize the Means of Carbon Removal: The Political Economy of Direct Air Capture', *Historical Materialism* (2021) 29: 1–46; Wim Carton, Jens Friis Lund and Kate Dooley, 'Undoing Equivalence: Rethinking Carbon Accounting for Just Carbon Removal', *Frontiers in Climate* (2021) 3: 1–7; Andreas Malm, 'Planning the Planet: Geoengineering Our Way Out of and Back into a Planned Economy', in J. P. Sapinski, Holly Jean Buck and Andreas Malm (eds), *Has it Come to This? The Promises and Perils of Geoengineering on the Brink* (New Jersey: Rutgers University Press, 2021), 143–62; Wim Carton, 'Carbon Unicorns and Fossil Futures: Whose Emission Reduction Pathways is the IPCC Performing?', in ibid., 34–49; Wim Carton, Adeniyi Asiyanbi, Silke Beck et al., 'Negative Emissions and the Long History of Carbon Removal', *WIREs Climate Change* (2020) 11: 1–25; Wim Carton, '"Fixing" Climate Change by

Mortgaging the Future: Negative Emissions, Spatiotemporal Fixes, and the Political Economy of Delay', *Antipode* (2019) 51: 750–69.

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